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Effects of age and gender on remote pointing performance and their design implications

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Abstract

The purpose of this research is to investigate the effects of age and sex on remote pointing movements. In addition, an attempt was made to incorporate possible age-related or sex differences into the design of a remote pointing user interface. The subjects were recruited from three age groups (elderly, middle-aged, and young) with equal number of both sexes. The participants were required to perform cursor positioning tasks using a remote pointing device. Their static hand stability and remote positioning time were recorded and analyzed. The remote positioning time was further separated into two components: initial submovement duration and adjustment submovement duration. The results reveal that age-related effects reduced the subjects' ability to perform remote pointing tasks and also maintained hand stability. However, sex differences had no significant effect on either performance. Moreover, the results also reveal that remote positioning movements for the young group were mostly completed in their initial submovement phase, while the elderly subjects spent most of their movement time on the fine adjustment phase. In light of the fact that different age groups exhibit different kinds of movement behavior patterns, suggestions for the design of signal sensitivity, target features, and display/control gain in remote pointing user interface were outlined.

Relevance to industry

Investigations on the variation in physical and psychomotor capabilities between the sexes and between different age groups which affect remote pointing performance will facilitate the design of remote pointing user interface. This study investigated the effects of age on remote pointing actions and outlined some suggestions for the design of remote pointing user interface.

Keywords: Age differences; Sex differences; Remote pointing; User interface design

1. Introduction

The remote control device is a recently developed technology with many potential applications. Using a remote control device, a person can

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stand or sit at a distance from the computer screen and control cursor movement. This remote control capability and operational intuitiveness makes remote pointing devices suitable for dynamic environments such as computer control rooms, family entertainment systems, and multimedia presentation systems. Because the remote control device has such a wide range of applications, the users of remote pointing systems will necessarily include males and females of all age groups. The variation in physical and psychomotor capability between the sexes and between different age groups (Sharit and Czaja, 1994) which affect remote control performance should, therefore, be studied to facilitate the design of remote control user interface in future.

When using a remote control device, the user primarily uses his/her hand and upper arm to hold and manipulate the device. The users' effectiveness in performing such a task is dependent primarily on their psychomotor ability. In general, the free movement permitted by a remote pointing device makes it more difficult to manipulate than desktop pointing devices such as mouse devices and trackballs. This can be attributed to the fact that in the use of the desktop pointing device, the user is operating in a two-dimensional environment and is obtaining feedback also from a two-dimensional environment. On the other hand, with a remote pointing device, the user is operating in a three-dimensional environment, but is getting feedback from a two-dimensional environment. The relationship between a two- and a three-dimensional environment clearly gives rise to greater difficulty than a relationship between two two-dimensional environments.

In addition, when using a mouse, the support of the table surface and the static friction prevent the user's hand from generating tremors when his/her hand is at rest. The same is true when using a trackball or joystick, where support for the wrist or elbow prevents or reduces hand tremor. When using a remote pointing device, on the contrary, hand movement is usually totally free (see Fig. 1), with no support for the hand or lower arm. Consequently, a higher level of tremor than with other pointing devices is usual. Because remote pointing devices may be subjected to a higher level of tremor than other types of pointing devices, they should be designed to distinguish between the user's movement instructions from involuntary tremor. It is, therefore important to ascertain the degree of stability that a user can maintain.

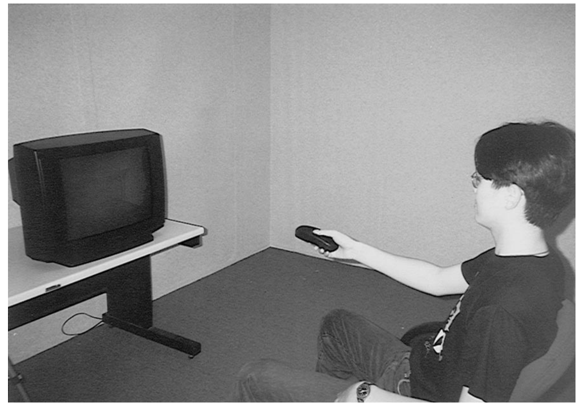

Fig. 1. User's position for remote pointing tasks.

To maintain a stable posture is quite a complex procedure. This postural maintenance process can be divided into three stages (Downton, 1990; Lord and Ward, 1994): (1) input of peripheral sensory information, (2) central processing of data, and (3) effector response action. It is important to note that the peripheral sensory information required to maintain a stable posture is derived from vision, proprioception, and the vestibular system, of which proprioception is the most important for maintaining a stable posture. However, visual feedback gains importance with increased age (Lord and Ward, 1994).

Previous researches have shown that the three functions required to maintain a stable posture all deteriorate with age (Colledge et al., 1994; Stelmach et al., 1989; Woollacott et al., 1986). For example, Stelmach and Sirica (1987) have argued that older people have higher proprioceptive thresholds to passive movements and thus are less accurate at reproducing and matching joint angles. Evidence for impairment of the central integrative processes comes from the study conducted by Teasdale et al. (1991). The work of Colledge et al. (1994) showed that peripheral nerve conduction velocity decreased with age, and that reduced muscle bulk also leads to deterioration of the response of effector.

Moreover, older people were found to be less accurate at reproducing and matching joint angles (Kokmen et al., 1978). Although age-related impairments at the three stages of postural control have been documented, these studies have addressed the effects of aging on overall posture, and few studies have been conducted which focus on the steadiness of the arm and hand. This study will, therefore, concentrate on arm and hand steadiness. Furthermore, Charness and Bosman (1994) indicated that there is an interrelation between age and sex in a person's movement control capability; this study will also look into the effects of sex on hand steadiness.

The process of remote pointing also affects the efficiency with which remote pointing actions are performed. The remote pointing process can be divided into two phases: the approach phase and the entry phase, which are the same as 'travel time' and 'adjust time' as defined by Jenkins and Connor (1949). The sum of travel time and adjust time equals the total time it takes to complete the whole positioning action. In order to increase the efficiency with which remote pointing movements are performed, in other words, reducing the total movement time needed, requires an understanding of the two phases that constitute the whole movement. The results should then be incorporated into the design of the interface and the system parameters used by the remote pointing device.

Owing to the different characteristics of user groups, the optimal parameters may vary from group to group. For example, Morgan et al. (1994) found that in the performance of free hand positioning tasks, the elderly were likely to exhibit greater hesitancy and require more submovements in the performance of tasks. Carey et al. (1994) found that the tracking performance of the elderly was inferior to that of younger subjects. These studies all point to the fact that the deterioration due to age creates certain differences between the ability of young and old in the performance of pointing movements; and it is important that these differences should be taken into account in the design of parameters for remote pointing devices.

Apart from age, psychomotor ability may vary according to sex. Generally speaking, the velocity of hand movement of females are slower than that for men (Ives et al., 1993). Charness and Bosman's (1994) study also indicated that women were less able to control the movement of their limbs than men. Therefore, in setting up system parameters for a remote pointing device, the performance characteristics of the two sexes and of different age groups have to be taken into account. The second aim of this study is thus to investigate these different pointing performance characteristics, and by clarifying the movement mechanisms of different user groups, formulate reference materials for system parameters in remote pointing devices.

2. Method

2.1. Subjects

48 healthy, self-declared right-handed volunteer subjects participated in this study. All subjects had normal or corrected-to-normal vision. The subjects were divided into 3 age groups. Each age group was further divided into male and female groups. Each single sex group consisted of 8 participants. These 6 subject groups were: (1) young male group ($M = 19.8$ years, SD $= 1.0$ years), (2) young female group ($M = 21.1$ years, SD $= 1.6$ years), (3) middle-aged male group ($M = 44.8$ years, SD $= 3.1$ years), (4) middle-aged female group ($M = 46.1$ years, SD $= 2.7$ years), (5) elderly male group ($M = 66.1$ years, SD $= 3.0$ years), and (6) elderly female group ($M = 64.5$ years, SD $= 3.3$ years). None of the subjects had ever used a computer remote pointing system before.

2.2. Apparatus

In this experiment, we used a Selectech Air Mouse™ remote control system as the cursor control device. Subjects controlled the cursor from a distance by a hand-held remote control device. An Air Mouse™ base station acted as the receiver for control inputs and was located directly beneath the display monitor. Transmission between the Air Mouse™ remote controller and base station is via an infrared (IR) system. The remote controller is a rectangular device with dimensions of $15\,(L) \times 6\,(W) \times 4\,(H)$ cm and a weight (with batteries) of 165 g.

A PC-486 compatible was used to control the sequence of events and record the data. The task was presented on a 20″ NEC Corp. MultiSync FG color monitor. This display has 1280×960 pixel resolution with 0.3175 mm per pixel. The screen was adjusted to be in the region of $\pm 15^\circ$ of subject's line of sight.

2.3. Procedure

Subjects were asked to perform discrete target acquisition tasks. Using the Air Mouse™, the subject was required to move the cursor from the center of the home position to the target. The home position was defined as a 10 mm circle in the center of the screen. The target could appear in any position around the home position. Three movement amplitudes (6, 9, and 12 cm) and three target widths (1, 1.5, and 2.5 cm) were used. These nine combinations can be converted into eight different levels of Fitts' Index of Difficulty (Fitts and Peterson, 1964) – i.e., 2.26, 2.85, 3, 3.26, 3.58, 4, 4.17, and 4.58 bits; the combination of a 1 cm target width and a 6 cm movement amplitude yielded the same Fitts' Index of Difficulty (i.e., 3.58 bits) as that of a 1.5 cm target width and a 9 cm movement amplitude. The experiment was, therefore, of a two-between (age and sex) and two-within (target width and movement amplitude) mixed design.

During the experiment, subjects were seated at a distance of 2.5 m from the display screen. At the beginning of each trial, subjects were instructed to move the cursor to the home position. They were required to keep the cursor within the home position for 5 s, until a beep sounded and a target (a red circle) appeared on the screen. Subjects were then required to move the cursor to the target as quickly as they could after hearing the start signal. To ensure that the subject was ready to respond, there was a 3 s interval between the target appearance and the start beep. After the cursor had remained within the boundary of the target for 200 ms, the target would disappear, completing the trial. To commence the next trial, the subject was instructed to return the cursor to the home position.

The experiment was conducted over a period of 3 days, with 5 sessions a day for each subject. A total of 9 different combinations of movement amplitude $\times$ target width were tested in each session, with each combination being repeated 8 times for a total of 72 trials in a session. The configuration and order of each trial within a session were randomly generated. To reduce the effects of fatigue, subjects were allowed to rest between trials and there was a 10 min rest between each session.

2.4. Performance measures

Two main performance measures were recorded during the experiment: (1) static hand tremor, and (2) total movement time.

Static hand tremor is the measure of the subjects' ability to maintain their hands in a stable posture. Static hand tremor was defined as the average difference between one sampled cursor position on the display screen and a subsequent cursor position. These cursor positions were recorded one-second after the cursor moved to the home position till the moment the target appeared. The sampling interval lasted for 4 s. The sampling rate of cursor positions was 5 Hz. That is, there were 20 cursor positions recorded and calculated for each trial.

Total movement time is the time needed to complete a discrete pointing movement defined as the time elapsed from when the cursor left the home position until the cursor moved into the target area. For a further examination of the effects of age and sex on the microstructure of remote positioning movements, the trajectory of each movement was parsed into two submovements: (1) initial submovement, and (2) adjustment submovement.

The parsing algorithm used in this experiment is similar to those developed in earlier studies by Jagacinski et al. (1980) and Walker et al. (1993). The initial submovement duration was deemed to begin as soon as the cursor moved outside the home position. It was considered to terminate when (1) the velocity of the cursor changed sign indicating a shift in movement direction, or (2) when the velocity of the cursor did not change sign but the movement decelerated and then reaccelerated toward the target again. The adjustment submovement duration was calculated from the ending of an initial submovement and was deemed to end as soon as the cursor moved into the target region.

3. Results

The experiment involved 15 sessions for each subject, each session consisting of 72 trials. The first 12 sessions were practice sessions and data obtained was not used for this study. Analysis of variance reveal that the last three sessions did not differ significantly for either static hand tremor, $F(2, 83) = 1.78$, $p > 0.1$, total movement time, $F(2, 83) = 1.78$, $p > 0.1$, initial submovement duration, $F(2,83) = 0.07$, $p > 0.1$, or for adjustment submovement duration, $F(2, 83) = 1.82$, $p > 0.1$, indicating that the subjects' performance had stabilized. Only data obtained from these last three sessions were used in this study.

3.1. Static hand tremor (ST)

Analysis of variance show that age had a significant effect on ST, $F(2, 42) = 14.85$, $p < 0.0001$. Post hoc analysis indicates that the mean ST for the elderly group (0.493 cm) was significantly higher than for the middle-aged (0.456 cm) and the young (0.362 cm) groups (Tukey HSD critical value = 4.122, $p = 0.01$). Moreover, the mean STs for the middle-aged group were significantly higher than the mean STs for the young group. However, there was no significant difference between the mean STs for the male subjects and for the female subjects, $F(1, 42) = 0.84$, $p > 0.1$. No significant interaction effect of age by sex was found, $F(2, 42) = 3.64$, $p > 0.01$.

3.2. Movement time (MT)

Analysis of variance show that age had a significant effect on MT, $F(2, 42) = 36.91$, $p < 0.0001$. Post hoc analysis indicates that the mean MT for the elderly group (1390 ms) was significantly larger than those for the middle-aged (1230 ms) and the young (882 ms) groups (Tukey HSD critical value = 4.122, $p = 0.01$). There was also a significant difference between the mean MTs for the middle-aged group and for the young group. Differences in sex had no significant effect on MT, $F(1, 42) = 0.36$, $p > 0.1$.

Both target width and movement amplitude had a significant main effect on MT, $F(2, 84) = 464.23$, $p < 0.0001$, $F(2, 84) = 793.39$, $p < 0.0001$. Specifically, MT increased from 898 to 1433 ms as target width decreased from 2.5 to 1.0 cm. In addition, MT increased from 910 to 1370 ms as movement amplitude increased from 6 to 12 cm.

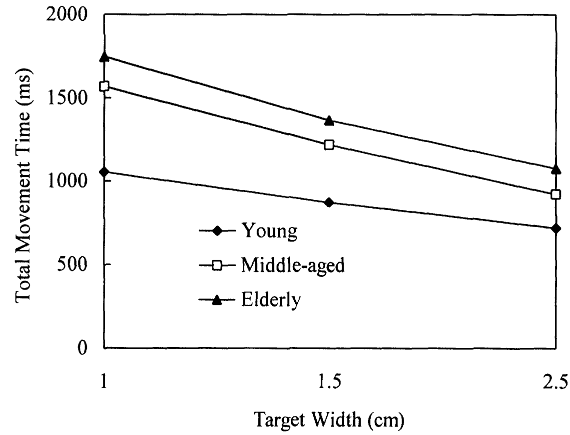

Fig. 2. Interaction of age and target width for the dependent variable total movement time.

Furthermore, there was a significant two-way interaction between age and target width, $F(4, 84) = 23.66$, $p < 0.0001$. This interaction suggests that the effect of target width on MT was larger in the elderly than in the young (see Fig. 2).

That remote pointing duration increased with movement amplitude, and decreased with the increase in size of the target, indicates that remote pointing does conform with Fitts' paradigm (Hoffmann, 1991; Drury and Hoffmann, 1992). We were, therefore, able to deduce Fitts' regression models modified by Welford (1968) for the three groups of subjects based on movement duration for each group in the context of different amplitudes and target sizes. Our Fitts' regression equations are as follows:

Elderly group:

$$MT = 132 + 498\log_2 A - 496\log_2 W,$$
$$r^2 = 0.96,$$

Middle − aged group:

$$MT = -197 + 512\log_2 A - 475\log_2 W,$$
$$r^2 = 0.98,$$

Young group:

$$MT = -33 + 297\log_2 A - 252\log_2 W,\quad r^2 = 0.98,$$

where MT is the average movement time, A the movement amplitude between the center of target and initial position, and W the target width.

3.3. Initial submovement duration (INI)

Analysis of variance shows that age had a significant main effect on INI, $F(2,42) = 156.94$, $p < 0.0001$. Post hoc analysis indicates that the mean INI for the young group (442 ms) was significantly larger than for the middle-aged (301 ms) and the elderly groups (301 ms), whilst there was no significant difference between the mean INIs for the middle-aged group and for the elderly group (Tukey HSD critical value $= 4.122$, $p = 0.01$).

There was a significant interaction between age and sex, $F(2, 42) = 17.57$, $p < 0.0001$. This interaction effect implies that the sex-related differences in INI were distinct in different age groups (see Fig. 3). For the young group, mean INIs for males (485 ms) were significantly larger than that for females (399 ms) (Tukey HSD critical value $= 3.645$, $p = 0.01$). For the middle-aged group, there was no significant difference between the mean INIs for males and that for females (Tukey HSD critical value $= 3.645$, $p = 0.01$). However, for the elderly group, the mean INIs for females (313 ms) were significantly larger than that for males (292 ms) (Tukey HSD critical value $= 3.645$, $p = 0.01$).

Target width had a significant main effect on INI, $F(2, 84) = 11.67$, $p < 0.0001$. Further analysis revealed that INI increased from 345 to 359 ms as target width increased from 1.0 to 2.5 cm. Moreover, there was a significant interaction between age and movement amplitude, $F(4,84) = 17.89$, $p < 0.0001$. Further analysis revealed that INI increased with movement amplitude in the young group, but this trend was not observed in the middle-aged and the elderly groups (Tukey HSD critical value $= 3.645$, $p = 0.01$) (see Fig. 4).

3.4. Adjustment submovement duration (ADJ)

Analysis of variance show that age had a significant main effect on ADJ, $F(2, 42) = 66.12$, $p < 0.0001$. Post hoc analysis indicates that the mean ADJs for the elderly group (1089 ms) was significantly larger than that for the middle-aged (929 ms) and the young groups (439 ms). Moreover, there was also a significant difference between the mean ADJs for the middle-aged group and that for the young group (Tukey HSD critical value $= 4.122$, $p = 0.01$). Also, no significant sex effect was found, $F(1, 42) = 1.37$, $p > 0.1$.

Both target width and movement amplitude had a significant main effect on ADJ, $F(2, 84) = 476.65$,

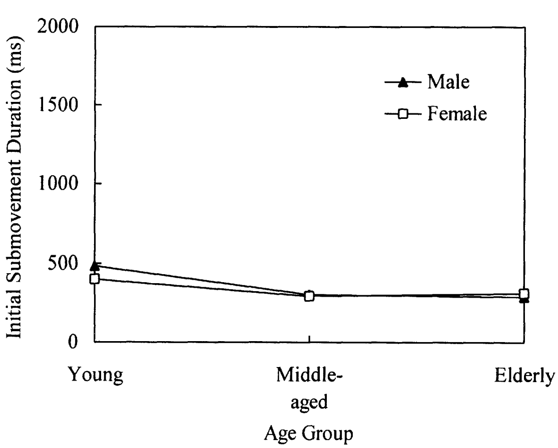

Fig. 3. Interaction of age and sex for the dependent variable initial submovement time.

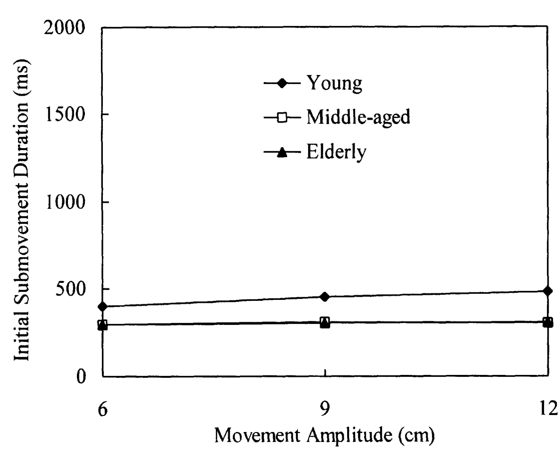

Fig. 4. Interaction of age and movement amplitude for the dependent variable initial submovement time.

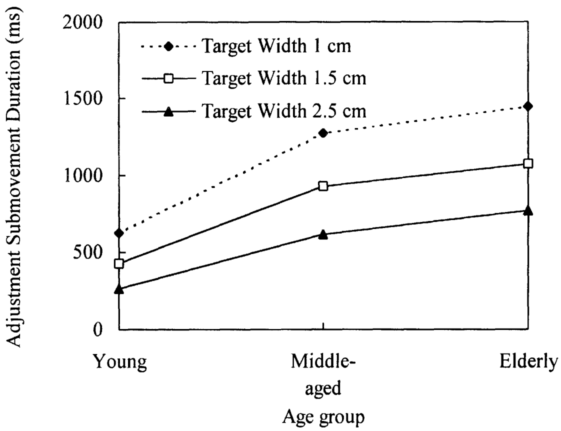

Fig. 5. Interaction of age and target width for the dependent variable adjustment submovement time.

$p < 0.0001$, $F(2, 84) = 570.65$, $p < 0.0001$. Specifically, ADJ decreased from 1088 to 539 ms as target width increased from 1.0 to 2.5 cm. However, ADJ increased from 578 to 1006 ms when movement amplitude increased from 6 to 12 cm.

A significant two-way interaction between age and target width was observed, $F(4, 84) = 23.11$, $p < 0.0001$. This interaction indicates that the difference between the mean ADJs for large targets and small targets was larger in the elderly group than that in the young group (see Fig. 5).

4. Discussion

4.1. User characteristics in performing remote pointing movements

The main purpose of this research is to investigate the effects of age and sex on remote pointing movements. In addition, an attempt was made to incorporate these possible age-related or sex differences into the design of a remote pointing user interface. Our results show that the performance of the elderly to maintain a stable posture has declined. We also found that the movement time to complete a remote pointing movement increased with age, an indication of deterioration in the ability of the elderly to perform remote pointing movements. The results show that the three test groups, divided by age, had significantly different average movement times; these differences suggest that the effects of aging begin to appear during middle age (about 45 years of age) or even earlier.

In order to better understand the effects of aging on the remote pointing mechanism, we divided the movement trajectory into two phases: the initial submovement phase and the adjustment phase. Analysis of the initial submovement phase indicates that the elderly and middle-aged groups had a shorter initial submovement duration than the young group; however, initial submovement duration between the elderly and middle-aged group did not differ significantly. In the young group, the initial submovement phase accounted for 55.2% and 45.1% of the total movement time of males and females, respectively (see Table 1), but in the elderly group, the initial submovement phase accounted for only 21.8% and 21.6% of total movement time in males and females, respectively (see Table 1). These results show that young people rely heavily on their initial submovement phase to complete the movement, while elderly people rely more heavily on the adjustment phase. Moreover, in the young group, initial submovement duration increased with movement amplitude, while initial submovement duration for the elderly was relatively unaffected by movement amplitude. These results reveal that the initial submovement possessed different characteristics in different age groups.

Analysis of the adjustment phase show that durations for the elderly and middle-aged groups were much higher than that for the young group. Moreover, target size had a significant impact on the length of the adjustment phase in the elderly and middle-aged groups, while its effect on the adjustment phase of the young group was negligible. This indicates that age differences also have a considerable influence on the adjustment phase of a pointing movement.

The reason for the different characteristics in the pointing mechanism of the different age groups may be as follows. Firstly, it might be due to different movement strategies adopted by the different age groups. It is generally accepted that older adults are slower than younger ones because they are more cautious and emphasize movement accuracy over movement speed (Goggin and Meeuwsen,

Table 1
Means and standard deviations of dependent variables versus subject group

	Young group				Middle-aged group				Elderly group			
	Male		Female		Male		Female		Male		Female	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ST	0.36	0.25	0.36	0.23	0.47	0.44	0.45	0.37	0.45	0.38	0.55	0.58
MT	879	352	884	435	1217	713	1241	791	1342	813	1451	883
INI	485	169	399	140	306	136	296	140	292	126	313	147
ADJ	394	371	485	416	911	704	945	775	1050	807	1138	875
p	55.2	–	45.1	–	25.1	—	23.9	—	21.8	—	21.6	—

Note. ST = static tremor (cm). MT = total movement time. INI = initial submovement time. ADJ = adjustment submovement time. p = the ratio of initial submovement time to total movement time. Dashes indicate the standard deviation was not estimated.

1992). Welford (1984) pointed out that subjects of different age groups adopt different movement strategies, with young subjects adopting higher risk strategies and elderly subjects being more inclined to adopt more conservative strategies. The use of a high risk strategy requires greater reliance on the initial submovement phase, while more conservative strategies adopted by elderly and middle-aged subjects place greater reliance on the adjustment phase. The adjustment phase is therefore longer for the elderly and middle-aged groups.

Apart from movement strategies, aging also results in the deterioration of motor programming and execution ability, which leads to differences in the mechanism of the pointing action in different age groups. For example, after controlling the movement strategy in older and younger subjects, Morgan et al. (1994) found that elderly users exhibited greater hesitancy and required a greater number of submovements. This shows that movement strategy is not the only factor exhibiting differences in the performance of pointing movements between young and old; age-related impairments of the movement execution systems should also be considered. Haaland et al. (1993), in an experiment conducted on pointing movement performance in various age groups, found that an increase in movement amplitude or target size led to a lower degree of acceleration in the elderly than in the young, indicating both a difference in strategy and a deterioration in performance capability. This deterioration is clearly a factor influencing different performance characteristics exhibited by young and old subjects. The deterioration in physical ability indicates that elderly people are less able to alter their initial submovement phase to meet different task demands. When the target was reduced in size, they experienced even greater difficulty in moving the cursor to the target area, a clear indication that they were much more affected by target size than were younger subjects.

The results show that gender has no significant effect on remote pointing time. As to the differences in performance ability for pointing actions between the sexes, previous researchers are not in agreement. Charness and Bosman (1994), Ives et al. (1993), and Landauer (1981) indicated that there are significant differences between males and females in the performance of pointing movements. On the other hand, Gan and Hoffmann (1988) suggested that there are no significant differences. The results of this study indicate that although the total time differences between males and females in performing remote pointing movements are not great, there is a significant difference in the process of the initial submovement, and that this difference was also affected by age (see Fig. 3). In the young group, the initial submovement duration for males was greater than for females. In the middle-aged group, there was no significant difference between the initial submovement durations between men and women. While in the elderly group, the initial submovement durations for women were significantly greater than that for men. The reason for this could be that aging causes males and females to adopt different movement strategies or that they undergo different changes in physiological mechanisms. A detailed explanation requires further study on this issue.

In sum, our results do not show any significant difference between the sexes in the performance of pointing actions. On the other hand, age not only led to a marked deterioration in the performance of remote pointing ability, but also changed the pointing mechanism. Therefore, age-related differences in remote pointing performance should be taken into consideration in the design of remote pointing environments and devices. The effects of age should not be over simplified, for these results show that aging does not simply lead to a lengthening of the initial submovement phase and subsequent adjustment movements but affects the movement mechanism in more subtle ways.

4.2. Implications for the design of remote pointing user interface

Our results show that age affects the performance of pointing actions while sex does not. Therefore, the following issues should be taken into consideration in the design of remote pointing user interface to make it suitable for users of different ages.

1. Signal sensitivity. The signal sensitivity of a pointing device will enable the system to differentiate between the user's commands and involuntary tremor. This is especially important in the design of a remote pointing device in which tremor can easily occur. Due to the differences in steadiness between user groups, the signal sensitivity should take into account the user's hand stability. A high sensitivity has a rapid response to the user's commands, but if the user exhibits tremor, the cursor will flicker on the screen, increasing the visual load for the user. On the other hand, while low sensitivity prevents such flickering on the screen, the slow response of the cursor to the initial movement can lead to bursts of movement and overshooting the target.

   Our results indicate that mean static tremor increases with age, which indicates that the hands of the elderly are less steady than that of the young. These results, therefore, suggest that a lower level of signal sensitivity will be preferable for older users, while younger users should be able to select a higher level of sensitivity. As the variations in mean static tremor in all three age groups are relatively large (see Table 1), an adjustable setup for signal sensitivity is recommended.
2. Target attributes. Our results indicate that both movement amplitude and target width had a considerable effect on the remote pointing ability of the three age groups. Therefore, in the design of the remote pointing user interface, movement amplitude and target size are both factors that must be considered if the efficiency of different age groups is to be increased.

   As regards movement amplitude, the larger the amplitude, the longer the adjustment duration in all three groups. Although this increase was not marked in the initial submovement phase of the elderly and middle-aged groups, it had a significant impact on the initial submovement phase of the young group. Total movement time for the three age groups increased with movement amplitude which indicates that a smaller movement amplitude is preferable. In other words, in a graphic user interface, icons or menus that the user will need to select should be grouped rather than scattered across the screen.

   As to target size, our results show that adjustment duration decreased in inverse relation to target size. Conversely, increased target size actually increased initial submovement duration in the three age groups; but overall movement time decreased. Therefore, large target size makes it easier to perform pointing actions and should be considered in the design of the interface. Our results also indicate that Fitts' law is able to accurately predict remote pointing movement duration for all three age groups ($r^2 > 0.96$). The three Fitts' regression models provided by this study, should, therefore, prove a useful

predictive model for interface designers to use in the design of remote pointing interfaces.
It is important to note that, when using a computer graphical interface, the user can use the cursor to approach the target (e.g., icon or menu) from different directions. MacKenzie and Buxton (1994) point out that when the target is a rectangular object, it possesses height and width characteristics. In this kind of two dimensional task, the design of the target should take into account the angle of approach. They suggested that the definition of target width should be replaced by the width of the approaching angle (W′ model), or the smaller of the length and width of the target should be selected as the new target width (Smaller-of model). Although MacKenzie and Buxton's (1994) model has already been validated, it still lacks target measurement design guidelines for use in a remote control environment. Since the remote positioning times increase substantially when target size is reduced from 1.5 to 1 cm (see Fig. 2), this indicates that the boundary line after which remote control performance deteriorates is around 1.5 cm (at a remote distance of 250 cm). Converted into visual angle, it is about 21 min (i.e., 0.35°). Therefore, when using a graphical interface, a target with a visual angle no less than 21 min is preferred.

3. Display/Control (D/C) gain. D/C gain is one of the most widely used parameters in the design of pointing devices (Arnaut and Greenstein, 1990). D/C gain will influence not only the user's movement time, but also the ratio between approach time and adjustment time proportional to the total movement time (Jenkins and Connor, 1949). According to Jenkins and Connor (1949), the lower the D/C gain value, the shorter the adjustment duration of a pointing movement. The approach duration, on the other hand, will be increased. With a high D/C gain value, approach duration decreases, but adjustment duration increases. At present, there are no standards on which the settings of D/C gain can be based. Sanders and McCormick (1993) suggested that in the absence of such a standard, the characteristics of pointing devices should be used as the basis of deciding D/C gain settings.

Our results show that younger subjects have a higher level of performance in executing pointing actions; their heavy reliance on the initial submovement phase to perform these actions conforms to the conservative movement model proposed by Welford (1984). Performance by elderly subjects, on the other hand, exhibited marked deterioration and a reliance on closed-loop feedback adjustments to complete the pointing action, also conforming to Welford's conservative strategy. According to Jenkins and Connor's (1949) assertion, a lower D/C gain should be used to compensate for elderly users' impaired micro-adjustment ability and preference for conservative strategies. A higher D/C gain should be provided for younger users to take advantage of their stronger ability, preference for high risk strategies and to fulfill their demand for greater speed in cursor movement. Adjustable D/C gain should therefore be provided to meet the needs of different user groups.

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