

Design of vehicle instrumental panel for older adults - Effects of viewing distance, display form, and switch arrangement on secondary task performance -

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Abstract— The effects of age, viewing distance, arrangement of switches and display form on performance to the design of display and control systems friendly to older adults were discussed. A dual-task experiment was conducted in which the primary task was first-order tracking. The secondary tasks included control of an air conditioner, the operation of a radio, and the operation of a CD/MD, by means of a steering wheel mounted switch. The switch was either vertical or cross arrangement. In both-hands switch arrangement condition, the operation was carried out with two hands using both left vertical switch and right cross switch. In one-hand switch arrangement condition, the operation was carried out with only one hand using either left or right cross switch. The display was arranged in front of a participant. The display form was either left or right display. The viewing distance conditions were 60, 80, and 100cm. When the right display form was used, both one-hand (using only right cross switch) and two-hands arrangements (using both left vertical and right cross switch) were selected. When the left display form was used, both one-hand (using only left cross switch) and two-hand arrangements (using both left vertical and right cross switch) were selected. As predicted, age affected the performance measures (percentage correct, task completion time, and tracking error). The viewing distance also affected performance (percentage correct). Both display form and switch arrangement also affected performance (task completion time). Such results should be taken into account when designing display and control systems in man-vehicle systems.

1. INTRODUCTION

With the growth of intelligent transportation systems (ITS), such as car navigation systems or hands-free cellular phones, driving is becoming more and more complex (Noy 1997). As much of the information provided contains texts and images, drivers are apt to become distracted and inattentive. Driving a car places a characteristically heavy workload on visual perception, cognitive information processing, and manual responses (Wickens et al. 1983). Drivers often simultaneously perform two or more tasks; for example, they adjust the volume of a radio or CD player and control the air conditioner to adjust the temperature while driving. Such sharing of attention may lead to dangerous situations.

1.1. Displays and controls in automobiles

Previous research in the area of displays and controls for secondary devices in automobiles is notable for the lack of reported work on compatibility. Most research discusses design of the display or the control, but not the way in which they are to operate together, which includes effects of compatibility.

Lambel, Kauranen, Laakso, and Summala (1999) and Lambel, Laakso, and Summala (1999) discussed the relationship between display location and performance in car driving situations. Lambel, Laakso, and Summala (1999) reported that the driver's ability to detect the approach of a decelerating car ahead was affected by the display location. Waller and Green (1997) examined switch type and its location, and pointed out a lack of consensus as to where the control should be located. Proper control (switch) location must be one of the important factors to assure fast responses of drivers.

Makiguchi et al. (2003) demonstrated that steering wheel mounted controls were more effective than controls on the instrumental panel. However, they did not examine the effectiveness of steering wheel-mounted switches by taking the display location factor into account. Although Wierwille (1993) stated that in-car controls and displays should be designed by taking visual and manual demands into account, he did not give guidelines for where the displays and controls should be located. Murata and Moriwaka (2005) investigated how the number and arrangement of steering wheel mounted switches interactively affected performance. They found that the cross-type arrangement with three switches provided best performance and highest psychological rating.

These studies did not take the memory factors into account to the design of display with layered structures. The display design also should consider the findings on eye movement characteristics that horizontal eye movement is faster and easier than vertical eye movement. Although Murata and Moriwaka (2005) investigated how the control should be designed without taking the display factors into account, the interaction between display and control factors must be investigated in order to obtain a more proper design guideline.

1.2. Effects of driver age

Older adults may have more difficulty in operating a vehicle than younger adults. 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). These authors reviewed the literature in movement control and discussed the effects of age on cognitive-motor capabilities in driving, from the viewpoint of movement science. Imbeau et al. (1993) discussed how the aging factor affected display design and driving performance. They made an attempt to provide designers with integrated performance data that helped them answer design questions and evaluate design alternatives. They presented a model that can predict performance (glance time of the display) using age, character size of the display, and contrast of the display. However, they did not discuss the effects of controls. Smith et al. (1993) reviewed the current databases applicable to automobile design. They pointed out that design approaches and data used in automobile design are mostly for a young population. The design approach and data suitable for an older population has not been provided. They did however review data on the characteristics and problems of older drivers, including physical and motor, sensory and cognitive changes. It is pointed out that working memory of older adults is inferior to that of young adults. Mead, Batsakes, Fisk and Mykityshyn (1999) identified the need to address working memory concerns when designing computer interfaces, in particular, for older adults. As the display and control systems of automobile is becoming more and more complex with the growth of intelligent transportation systems (ITS), it is predicted that memory workload would be a crucial factor and distract older drivers. The display design that takes the memory workload would be important especially for older adults.

1.3 Effects of viewing distance

There seem to be few studies that examined the effects of viewing distance on the driving performance. There are a few studies that investigated how viewing distance in VDT tasks affected the task performance. Jaschinski-Kruza (1990) that during work at VDT most people prefer viewing distance greater than 50cm. Jaschinski-Kruza (1991) found that their participants chose viewing distance between 51 and 99cm with a mean value of 74cm. Jaschinski, Heuer, and Kylian (1999) found that screens at about 66cm induced more reported eye strain than screens at 98cm. Based on these studies, it is inferred that longer viewing distance reduces eye strain even in driving environment. Moreover, in driving environment where focal accommodation between far (scenes in front of an automobile) and near (display in automobile cockpit module) points, it might be expected that focal accommodation is less under the condition of long viewing distance than under the condition of short viewing distance. This might be more desirable for older adults whose focal accommodation degrades with age.

On the basis of discussion above, it is questionable how the display format, the arrangement of controls (switches), the

viewing distance, and age affect the performance. On the basis of the discussion above, it was hypothesized that long viewing distance would lead to better performance especially for older adults. We also hypothesized that the proper display format, the proper arrangement of controls, and the effective linkage of these two design factors would lead to higher performance for both age groups (young and older adults).

If the effects of the factors above mentioned on performance measures are identified, the results can be very useful to automotive ergonomics engineers to design display and control systems that are proper for each age group. In this research, the effects of viewing distance, display format, arrangement of switches on the performance to the design of display and control systems were explored as a function of age.

2.METHOD

Drivers in the experiments performed a simulated steering task. The secondary tasks included the control of an air conditioner, the operation of a radio, and the operation of a CD/MD. The control was conducted using either steering wheel mounted switches. The display was arranged on the appropriate panel in front of the participant. Participants were required to perform the secondary task while performing the primary task.

2.1. Participants

Fifteen participants took part in the experiment. Ten were male adults aged from 62 to 81 years. All had held a driver's license for 30 to 40 years. Five were male undergraduate students aged from 20 to 23 years and licensed to drive from 1 to 3 years. Stature of participants ranged from 160 to 185 cm. The visual acuity of the participants in both young and older groups was matched and more than 20/20. They had no orthopedic or neurological diseases.

2.2. Apparatus

The experimental system is illustrated in Figure 1. The main components were (i) a pursuit tracking system (a personal computer with an I/O board, rotary encoder, and steering wheel). This PC was connected to a projector to display a tracking task in front of the participant.), (ii) a personal computer that was used to display speedometer and operational information, and (iii) a personal computer equipped with an I/O card and used to enable the participant to operate switches. The CRT was placed in front of the participant. In Figure 1, the display location is shown as the visual angle from the eye-point of the participant. A 15-inch CRT was in front of the participant. The visual angle subtended by the front display is in fact different from that subtended by the left display.

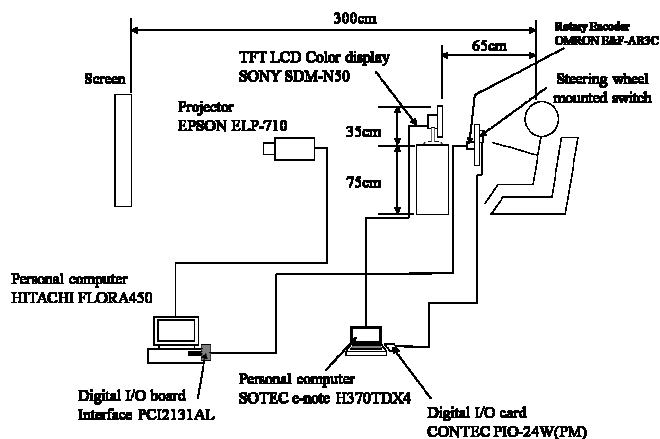


Figure 1. Outline of experimental setup and apparatus.

2.3. Task

There were three types of secondary tasks: (i) control of an air conditioner (temperature, air flow, direction of air flow, and A/C -when the air conditioner is on, this switch must be on); (ii) MD/CD operation (selection of music, volume, set up of the repeat function, and switching between MD and CD) and (iii) radio operation (selection of radio station, volume, auto-tuning function, and switching between AM and FM).

A sample task was presented as follows: "Please turn on the air conditioner and adjust the temperature to 27 °C . "Conducting such a task required pressing a switch a minimum number of times. The participant, however, did not always complete the pre-specified task with the minimum number of switch pressings. It is possible to perform the task with more switching than the minimum required. The participant must first touch switch 1 and select the air-conditioner control. Second, the participant selects A/C from the menu, which allows switching from heating to air-conditioning. Next, the information on the current temperature was shown on the second display (status display) in Figure 3. The participant adjusted the temperature to 27 °C by operating the left- and right-arrow switches. When the participant determined the final state, the "enter" switch placed on the right side was pressed. It was not until the participant pressed the "enter" switch that the task was completed. Once the task was completed, a new task was shown on the task window to be performed by the participant.

The tracking task was one-dimensional with the horizontal position of a target line changing pseudo-randomly. The participant was required to follow the movement of a target line with the shorter vertical line controlled by a steering wheel. The target signals were produced by summing a number of harmonically related sinusoids of different phases (fundamental frequency 0.007Hz). This allowed several pseudo-random signals that were non-periodic within the duration of the tracking task. The signal bandwidth was set to 0.2 Hz (± 0.1 Hz). In such a way, the position of the vertical target line was

generated. The position of the vertical target line changed every 1.5 s. The position of the shorter vertical line controlled by the steering wheel was sampled every 0.1s. This means that the tracking task was one of step input types, rather than continuous. The tracking dynamics were first order in which the cursor responded proportionally to the time integral of the steering wheel (control) position. These dynamics simulate the yawing response of a motor vehicle and hence approximate the visual information processing demands of driving. The error of the vertical cursor from the target line was measured during the tracking duration. The root mean square of the error values was calculated and automatically written to the computer data file.

2.4. Design

The switch was either a vertical or cross arrangement as shown in Figure 2 and Figure 3. In both-hands switch arrangement condition, the operation was carried out with two hands using both left vertical switch and right cross switch (See Figure 2). In one-hand switch arrangement condition, the operation was carried out with only one hand using either left or right cross switch (See Figure 3). The display was arranged in front of a participant. The display form was either left or right display. The viewing distance conditions were 60, 80, and 100cm. When the right display form was used, both one-hand (using only right cross switch) and two-hands arrangements (using both left vertical and right cross switch) were selected.

An example of right display form is demonstrated in Figure 4. When the left display form was used, both one-hand (using only left cross switch) and two-hand arrangements (using both left vertical and right cross switch) were selected. An example of left display form is shown in Figure 5.

The experimental factors were participant age (young and older adults), display form (left and right), and switch arrangement (one-hand and two-hand arrangements). Age was a between-subject factor; others were all within-subject factors.

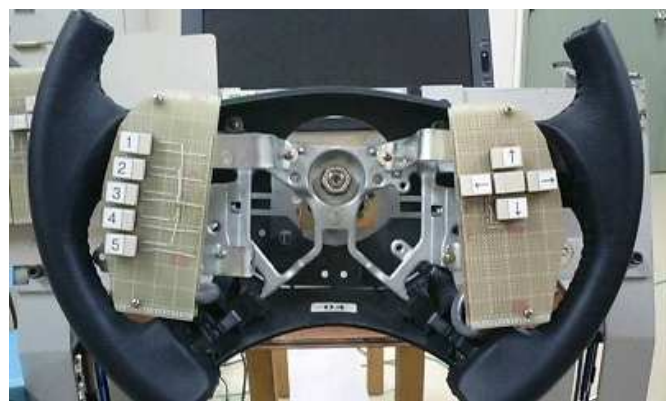


Figure 2. Both-hands switch arrangement condition.

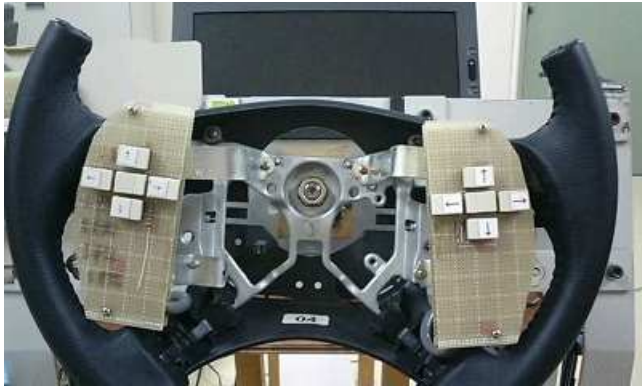


Figure 3. One-hand switch arrangement condition.

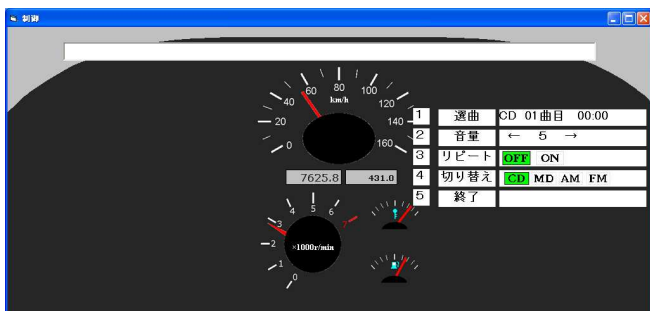


Figure 4. An example of right display form.

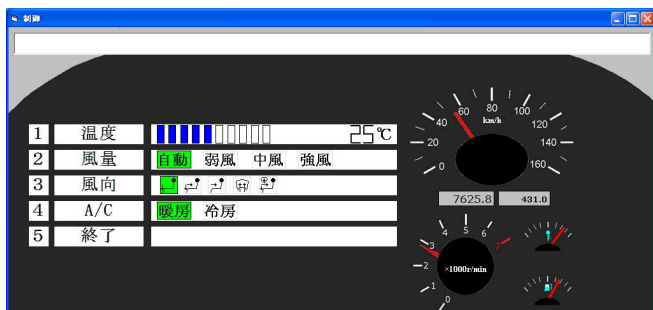


Figure 5. An example of left display form.

2.5. Procedure

The participant was asked to adjust his seat so that the task could be comfortably performed and the left-side console switches could be pressed by reaching his hand naturally. Before the experimental tasks, the contents of primary and secondary tasks were explained to each participant. Participants were allowed to practice before performing experimental tasks. When the experimenter judged that the participant clearly understood how to perform a task, the experiment was started. The participant was instructed to keep his left hand on the steering wheel when not performing a secondary task.

A dual-task was carried out. While a tracking task was carried out, one of the 12 conditions above (viewing distance (3 levels) x display form (2 levels) x switch arrangement (2

levels)) was simultaneously conducted. The order of performance of the 12 conditions was randomized across the participants.

For each combination of 12 conditions (viewing distance (3 levels) x display form (2 levels) x switch arrangement (2 levels)), psychological ratings on visibility of display and ease of switch press were carried out with a five-point scale (1=very poor, 5=very good).

The duration of the tracking task differed among the participants and ranged, because the total completion time of the secondary tasks differed among participants. The participants were required to keep the primary task stable and also to perform the secondary task as fast and accurately as possible.

2.6. Experimental measures

The experimental measures of performance were (i) mean RMS tracking error between a moving target and a controlled vertical cursor, (ii) mean completion time of secondary tasks, (iii) mean percentage correct performance of the secondary task, (iv) psychological rating on visibility of display and ease of switch press. Here a correct trial was defined as one in which the task was completed correctly, not necessarily with the minimum number of switching actions.

3. RESULTS

Percentage correct

A four-way (age by display form by switch arrangement by viewing distance) ANOVA was carried out on the percentage correct. Only a significant main effect of viewing distance ($F(2,26)=3.689, p<0.05$) was detected. In Figure 6, the percentage correct is plotted as a function of viewing distance. As a result of multiple comparisons, a significant difference of the percentage correct was found between 60 and 80 cm.

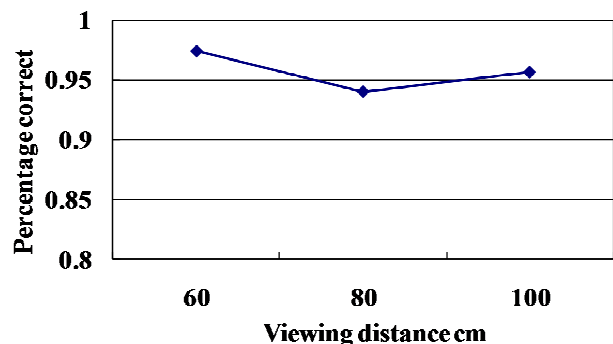


Figure 6. Percentage correct as a function of viewing distance.

Task completion time

A similar four-way (age by display form by switch arrangement by viewing distance) ANOVA was carried out on the task completion time. Only a significant main effect of age ($F(1,13)=10.152, p<0.05$), display form ($F(1,13)=6.322, p<0.05$), and switch arrangement ($F(1,13)=8.548, p<0.05$) was

detected. In Figure 7, the task completion time is plotted as a function of age. Figure 8 shows the task completion time as a function of display form. In Figure 9, the task completion time is shown as a function of switch arrangement.

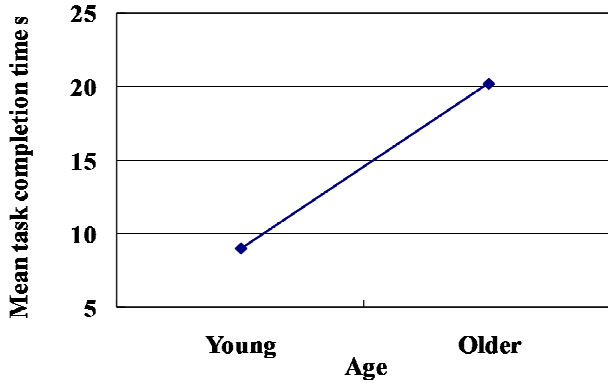


Figure 7. Mean task completion time as a function of age.

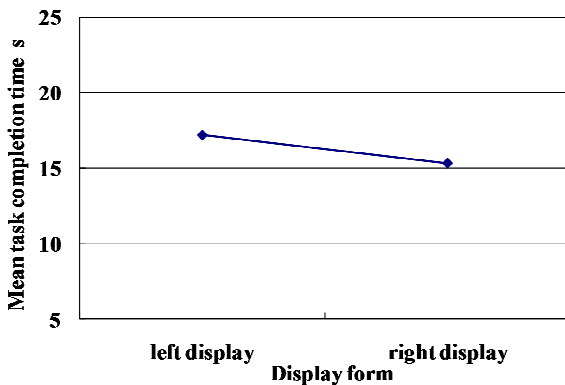


Figure 8. Mean task completion time as a function of display form.

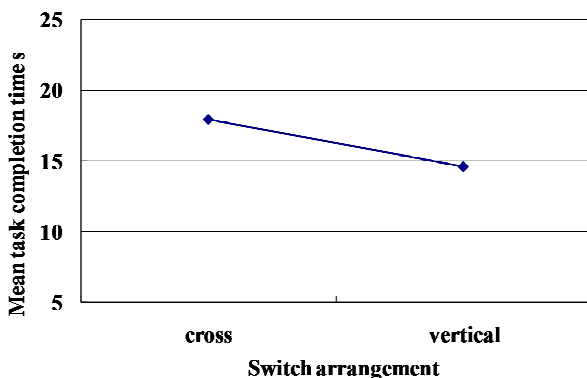


Figure 9. Mean task completion time is shown as a function of switch arrangement.

Tracking error

A similar four-way (age by display form by switch arrangement by viewing distance) ANOVA was carried out on the tracking error. Only a significant main effect of age ($F(1,13)=5.774, p<0.05$) was revealed. A significant age by switch location interaction ($F(1,13)=7.593, p<0.05$) was detected. In Figure 10, an age by switch arrangement interaction for the tracking error is shown.

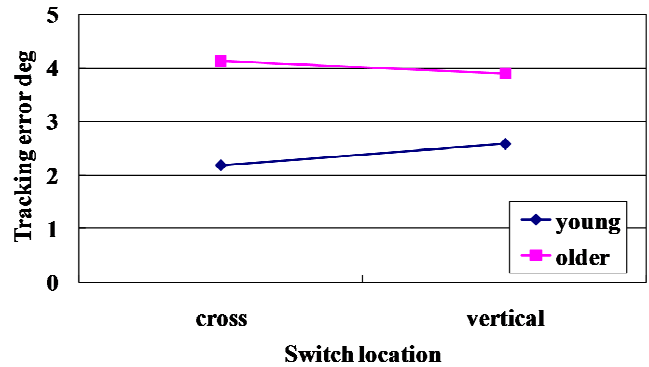


Figure 10. Interaction between age and switch arrangement for tracking error.

Psychological rating on usability

As a result of non-parametric test (Kruskal-Wallis test) carried out on the visibility of display, a significant main effect of viewing distance was detected ($p<0.05$). As for the ease of switch press, no significant main effects were detected. In Figure 11, the mean rating score on visibility is plotted as a function of viewing distance. As a result of Man-Whitney test, the visibility scores between 60 and 100 cm, and between 60 and 80cm were found to be significant.

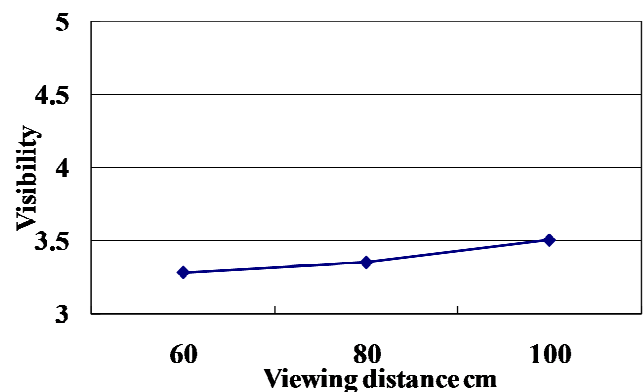


Figure 11. Mean rating score on visibility is plotted as a function of viewing distance.

4.DISCUSSION

The viewing distance affected the percentage correct (Figure.6). The percentage correct at the viewing distance of

80cm was the lowest. The longest viewing distance of 100cm led to higher percentage correct. As well as Jaschinski-Kruza(1990), Jaschinski-Kruza (1991), and Jaschinski et al. (1999) it seems that longer viewing distance reduces leads to higher performance.

As shown in Figure 7, the task completion time of older adults was significantly longer than that of young adults. As Figure 11 also shows, the tracking error of older adults tended to be larger than that of young adults. These differences might be due to the different cognitive-motor functions between young and older adults. In other words, these differences can be accounted for by the declined cognitive slowing, declined working memory capacity, and declined motor function of older adults (Goggin et al. 1989, Goggin and Stelmach 1990, Stelmach and Nahom 1993, Mead, et al., 1999). This might be because the compensated for any decline in perceptual speed, and memory capacity (Smith et al. 1993) and motor functions (Stelmach and Nahom 1993).

Moreover, as shown in Figure 8, the task completion time for the right display was significantly shorter than that for the left display. This might be related to the dominant eye of participants (All participants' dominant eye was right). The switch arrangement affected the task completion time, and the task completion time at the two-hand arrangement was significantly shorter than that at the one-hand arrangement (See Figure 9). In this study, when the information necessary for operation was presented to the right, one-hand arrangement was used, and only the right cross switch was used, and vice versa. Although the movement of hand and finger becomes complicated, the two-hand arrangement seems to assure higher performance. This means that the less number of switches does not necessarily lead to higher performance. Using both hands in the right place seems to enhance performance.

The psychological rating on visibility of display as well as the percentage correct supported the hypothesis that the longer viewing distance would lead to higher satisfaction or performance, because focal accommodation is less under the condition of long viewing distance than under the condition of short viewing distance. This is desirable for older adults, because their focal accommodation degrades with age.

The above discussion demonstrates that designers must notice the display format, viewing distance, and switch arrangement interactively and systematically, taking the age factor into account. From the viewpoint of universal design applicable to both young and older adults, the viewing distance should be take as long as possible for both age groups.

When the designer considers the display for a secondary switch pressing task, the switch arrangement and the display form should be took into account. It must be also noted that consideration of not only the factor related to display but also the factor related to control further enhances the performance of older adults.

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