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A Study of the Leg-Movement Characteristics of Young and Elderly People During Emergency Braking in Different Sitting Postures

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ABSTRACT: The number of traffic accidents and the number of fatalities are on a downward trend. On the other hand, the number of traffic accidents involving the elderly is on the increase. One of the reasons for this is the decline in driving ability due to aging. In this study, we focused the characteristics of the decline in driving ability such as the inability to brake sufficiently in an emergency. Specifically, by comparing two sitting postures (user-selected and instructed), we analyzed the characteristics of the accelerator pedal-to-brake pedal movement and the braking force of the elderly. In addition, the characteristics of aging were also analysed by comparing the results with those of younger subjects. The results showed that the step-over time was faster in the instructed posture for both the young and the elderly. The maximum braking force was stronger in the instructed posture for both the young and the elderly. There was no difference in braking force between the young and the elderly.

KEYWORDS: Human Engineering, Elderly Person, Driver Characteristics (C2)

1. Introduction

Since 2005, the number of traffic accidents has decreased for 14 consecutive years, and the number of fatalities has decreased for seven consecutive years since 2012. On the other hand, both the number of traffic accidents and the number of fatalities involving the elderly have increased[(1)]. The main reasons for this are demographic changes (an increase in the elderly population, due to the baby boomers reaching the age of 65 and over)[(1),(2)], human-body tolerance shifts, due to age-related changes in body shape (obesity)[(3)] and bone density[(4)], and the decline in driving ability in terms of cognition, judgement, and operation required for driving[(5),(6)].

The cognition and judgement characteristics of the elderly are as follows[(7)]:

(A) They often overlook stop signs and traffic signals,
(B) they often do not look for other vehicles because they believe that they cannot be there, and
(C) the number of vision-direction changes is small (i.e. the amount of visual information acquired may be small).

In addition, the following operating characteristics have been reported:

(D) They often fail to take evasive action,
(E) their reaction time to sudden jumps at intersections is slower than that of non-elderly people, and
(F) they often fail to brake sufficiently in an emergency.

In this study, we focus on (F): the inability to brake sufficiently in an emergency. It is assumed that the brake operation changes, depending on the sitting posture of the driver, and the exerted braking force changes simultaneously. Therefore, an analysis focusing on the sitting posture is necessary.

Yang et al.[(8)] investigated the myoelectric response of the arms and legs and the operational response to emergency braking. They found that the myoelectric response time was slower in elderly people and women than in young people, and that the maximum braking force was lower in women than in men in each age group. However, this study did not show the effect of changing the sitting posture because only one sitting condition was investigated.

In addition, Wu et al.[(9)] investigated the effects of aging, using 16 different arrangements of the brake and accelerator pedals during emergency braking. They found that all arrangements produced results that were specific to the elderly, and pointed out the effects of reduced muscle activity in the legs and the difficulty in bending joints as factors. However, again, only one sitting condition was used.

The purpose of this study is to clarify the characteristics of the accelerator-pedal-to-brake pedal movement and the braking force of elderly people by comparing two sitting postures: user-selected and instructed. In addition, we aimed to clarify the characteristics of aging by comparing the results with those of younger people.

2. Methods

A small passenger car (Toyota Vitz DBA-KSP90) was used in the experiment. The vehicle was used in a stationary state. The front and rear doors on the driver's side were removed, and the B-pillar was cut to make it easier to obtain the movement data from the experimental participants.

Figure 1 shows a schematic of the experiment. For braking, the experimental participants were instructed to quickly change from the accelerator pedal to the brake pedal, when the lamp in front of them lit up, and to press down as hard as possible as soon as possible. The experimental participants were also instructed to maintain their foot pressure while the light was on (2–3 s). Measurements were taken twice, and the timing of the braking was controlled by randomising the lighting of the lamp so that the experimental participants would not become accustomed to it. Measurements were taken of the braking force and the leg movements during braking.

The brake force was obtained by measuring the hydraulic pressure of the brake unit and converting it into a force at the pedal surface, based on the relationship between the moment arm and brake pedal. The leg movements during braking were captured from the side of the driver's seat using a high-speed camera (Sports Sensing GC-LJ20B) at 250 fps. The skeletal features of the experimental participants (acromion, greater trochanter, centre of the knee, peroneal exostosis, heel, toe) were marked with reflective markers on their clothes. The images were digitised using image-analysis software (DKH Frame-DIAZ V) to obtain 2D coordinates of the skeletal feature points, and the hip, knee, and ankle joint angles were calculated. The hip angle was defined as the angle between the line connecting the greater trochanter and acromion and the line connecting the greater trochanter and the centre of the knee. The knee angle was defined as the angle between the line connecting the centre of the knee and the greater trochanter and the line connecting the centre of the knee and the peroneal exostosis. The ankle angle was defined as the angle between the line connecting the peroneal exostosis and the centre of the knee and the line connecting the peroneal exostosis and the toe. An LED-type synchroniser (DKH) was installed to indicate the start of braking.

2.1. Experimental Participants

The experimental participants were healthy men with no abnormalities in their physical functions: 15 young men (20–25 years old, height: 171.6 ±4.0 cm, weight: 69.7 ±15.2 kg) and eight elderly men (65–71 years old, height: 170.4 ±3.9 cm, weight: 78.1 ±11.5 kg). The experimental participants were explained the contents of the experiment, and informed consent was obtained before the start of the experiment. This study was approved by the Ethics Committee of Teikyo University.

2.2. Sitting Postures

Figure 2 shows an example of the sitting posture of the experimental participant (height: 173 cm, weight: 73 kg) who is close to the average height and weight of all the participants in the experiment. Two types of sitting postures were established: user-selected and instructed, as shown in Figure 2. In the user-selected condition, the experimental participants were allowed to adjust the seat (slide and seat-back angle) and steering position by themselves to make the posture as comfortable as possible for normal driving. During this time, they were also asked to make minor adjustments to the seat and steering positions.

The instructed seating was set to a 100° hip angle, 115° knee angle, and 118° ankle angle, referring to the median of the appropriate range of joint angles in the sitting posture described in the literature[6], [10], [11], [12]. The experimenter adjusted the seat position using a protractor to match each joint angle. As in the user-selected position, the experimenter was given approximately one minute to familiarise himself with the control device, during which time he made minor adjustments to the seat and steering position so that each joint angle was more in line with the instructed angle.

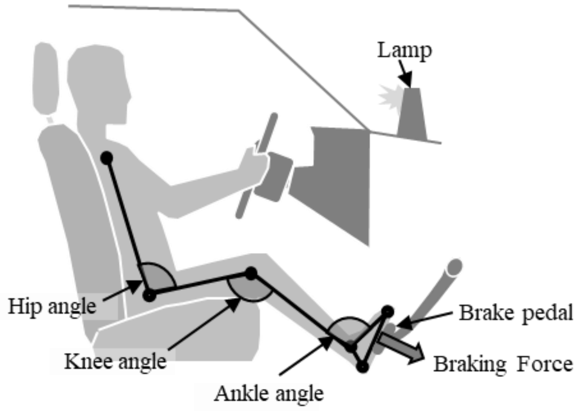

Fig.1 Schematic of the experiment

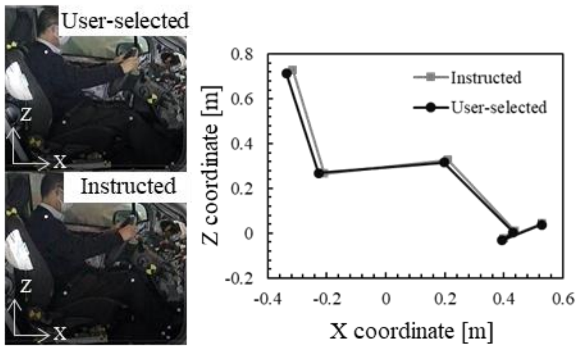

Fig.2 Example of sitting postures

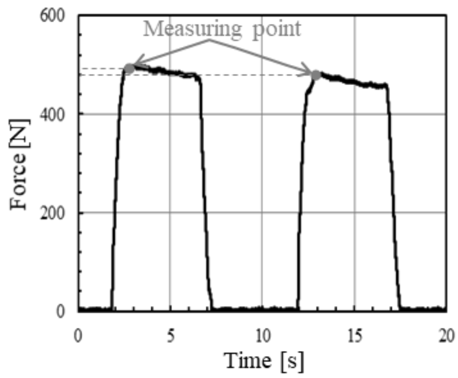

Fig.3 Measuring point for maximum braking force

3. Results

In this experiment, two measurements were taken for each of the two seated postures for each experimental participant. An example of the time-history diagram of the braking force is shown in Figure 3. The results of the maximum braking force were stronger the first time and weaker the second time. The other participants showed the same tendency and vice versa, and there was no regularity in the strength of the braking force.

The same tendency was observed for other results, such as sitting posture, step-over time, and leg movements, although the braking force is shown as an example in Figure 3. Therefore, in this experiment, the average values of the first and second times were used as the result.

Furthermore, by comparing the mean values of the experimental results of the young and elderly participants, the characteristics of the accelerator pedal-to-brake pedal step-over behavior by sitting posture and aging were extracted. Significant differences were determined by a two-sample unequal variance t-test, with $P<0.05$ considered significant. The mean and standard deviation are shown in each graph.

3.1. Sitting Postures

The differences in the sitting posture of the participants are shown in Figure 4. The joint angles in the instructed posture were significantly smaller than those in the user-selected posture for both the young and elderly (Hip: Young $p<0.001$, Elderly $p<0.001$, Knee: Young $p<0.001$, Elderly $p=0.002$, Ankle: Young $p=0.006$, Elderly $p=0.028$). In other words, the user-selected posture, which was adjusted by the experimental participants to be comfortable, had a larger joint angle than the instructed, and the posture was more stretched.

3.2. Step-over Time

The step-over time is the time from the first movement of the hip, knee, or ankle joint to the generation of the braking force when the lamp lights up. The results are shown in Figure 5. The step-over time was faster in the instructed posture than in the user-selected posture for both the young and the elderly (Young $p<0.001$, Elderly $p=0.049$). In the instructed posture, the step-over time was faster in the young than in the elderly (User-selected $p=0.138$, Instructed $p=0.021$).

3.3. Maximum Braking Force

Figure 6 shows the results of the comparison of the maximum braking force between the young and the elderly in different sitting postures. The maximum braking force of both the young and elderly was higher in the instructed than in the user-selected (Young $p<0.001$, Elderly $p=0.015$). However, there was no difference in the braking force between the young and the elderly in the two sitting postures (User-selected $p=0.256$, Instructed $p=0.081$).

Figure 7 shows the results of the scatter diagram of the change in the maximum braking force of the young and elderly, due to the different sitting postures. The results were higher than the straight line, "A," where the maximum braking force between the user-selected and the instructed was equal, except for two of the young and the elderly. When the regression lines of the data for the young and the elderly were compared, the slope of the elderly was shallower than that of the young.

4. Discussion

There was no significant difference between the height and weight of the younger and eldery experimental participants (height: $p=0.284$, weight: $p=0.096$). Therefore, it is considered that there was no effect of body size on the results of the experiment.

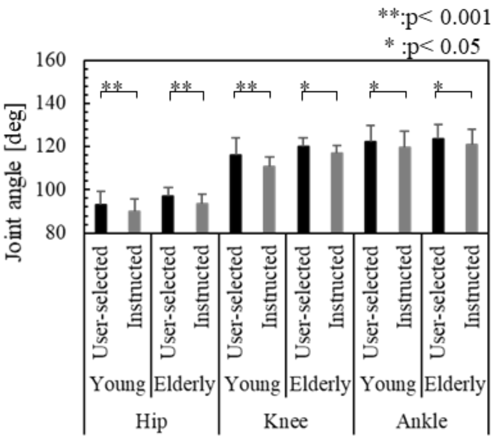

Fig.4 Joint angles in user-selected / instructed posture

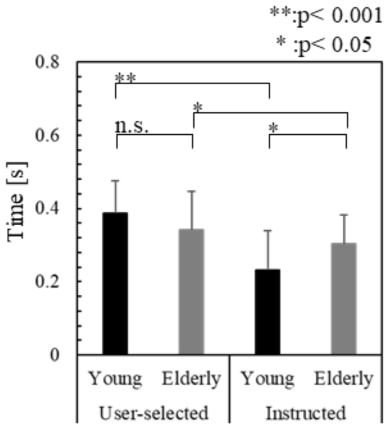

Fig.5 Step-over time

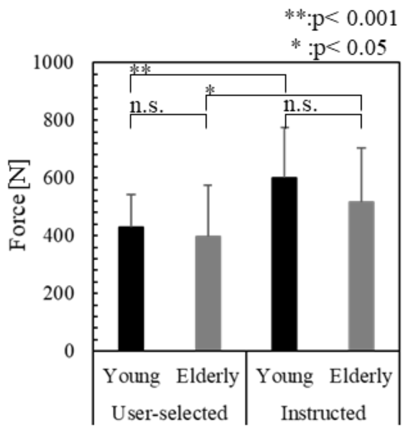

Fig.6 Maximum braking force

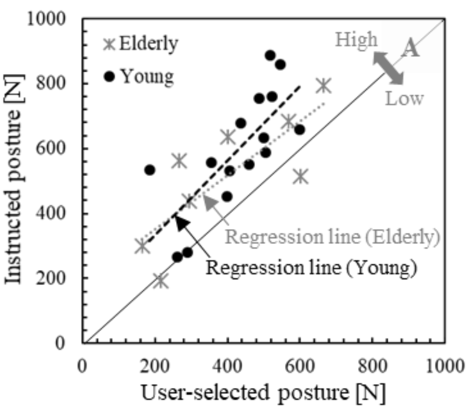

Fig.7 Comparison of maximum braking force

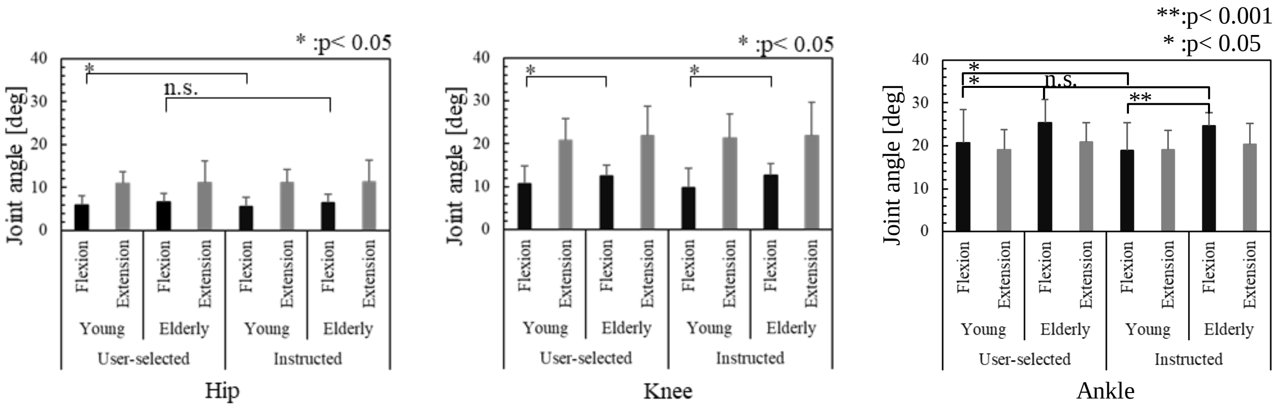

Fig.8 Maximum joint angle

In the previous section, experiments showed that the step-over time was faster and the maximum braking force was stronger when the sitting posture of the young and the elderly changed from user-selected to instructed. The difference between the two sitting postures was that each joint angle in the instructed posture was significantly smaller than that in the user-selected posture, for both the young and the elderly (Fig. 4). Therefore, it is thought that the step-over motions could be performed in a posture with more flexion of the leg than in the user-selected posture.

Figure 8 shows the maximum joint angle of the leg. It can be seen that the maximum joint angle of the hip and the ankle in the flexion of the young in the instructed decreased (Hip: p=0.04, Ankle: p=0.021), and step-over movements could be performed with a small change in the joint angle. In other words, the decrease in the change in the joint angle is one of the factors that made the step-over time faster.

Similar to the young, the elderly did not show a significant difference (Hip: p=0.287, Ankle: p=0.296). However, although there was no significant difference, the mean value of the change in the joint angle tended to decrease in the instructed posture in the elderly as well (Differences: Hip 0.278 deg, Ankle 0.773 deg), suggesting that the decrease in the change in the joint angle contributed to the speed of the step-over time.

In addition, there was no difference in the change in the leg extension related to the braking action between the different sitting postures, and between the young and the elderly. However, when the mechanism of the increased braking force in the instructed was considered, in terms of the series of actions from flexion to extension, it was thought that the braking force was increased because the instructed allowed the brake pedal to be depressed with a more vigorous extension of the flexed joint.

Furthermore, the maximum joint angle of the leg (Fig. 8) was larger in the knee and ankle of the elderly than in the young in the step-over movements (Knee: User-selected p=0.042, Instructed p=0.006, Ankle: User-selected p=0.012, Instructed p<0.001). In a previous study(13), it was pointed out that there was a difference in the movements due to aging between young and elderly people. However, under the experimental conditions of this study, there was no difference in the step-over time in the user-selected posture. In the instructed posture, the young were faster, but the maximum joint angle in the knee and ankle was larger in the elderly. Therefore, it is considered that there was no difference in movements due to aging in this study.

The maximum braking force (Fig. 6) was greater in the instructed than in the user-selected for both the young and the elderly; however, there was no difference in the maximum braking force between the young and the elderly in either posture. Next, it was found from Fig. 7 that a higher braking force could be generated by changing from the user-selected to the instructed position.

Comparing the regression lines of the data for the young and elderly, the slope of the elderly was shallower than that of the young. This means that there is no difference in the change in the maximum braking force between the young and the elderly because of the difference in sitting posture in the range where the maximum braking force is weak (e.g. approximately 200 N). However, in the range where the braking force is strong (e.g. around 400 N), the change in the maximum braking force, due to the difference in sitting posture, of the elderly is smaller than that of the young. In other words, in the range of high maximum braking forces, the change in maximum braking force due to differences in sitting posture was lower in the elderly than in the young.

The magnitude of the slope of the regression line of the time-history diagram of the braking force was compared between the two classes, with the largest number as the rate of change in the braking force [N/s]. We split the braking force into two groups: 0 N–100 N and 100 N–300 N. Figure 9 shows the slope of the rate of change from 0 N to 100 N. It was obtained by dividing the braking force by the time taken to generate the braking force ([N/s]). The results showed that the rate of change in braking force was higher in the instructed than in the user-selected for both young and elderly individuals (Young p<0.001, Elderly p=0.014). In the instructed posture, the rate of change in braking force was higher in the young than in the elderly (Instructed p=0.042).

Figure 10 shows the slope of the rate of change for 100 N to 300 N. The results showed that the rate of change in braking force was higher in the instructed posture for the young; however, there was no difference in the sitting postures for the elderly (Young p<0.001, Elderly p=0.121). Thus, the elderly showed a difference in sitting posture in the low braking-force range (0–100 N [N/s]), but not in the high braking-force range (100–300 N [N/s]). This tendency is considered to be the same as that of the regression line of the data of the young and the elderly in Fig. 7, where the slope of the elderly is shallower than that of the young.

However, the 0–100 [N/s] rate (Fig. 9) was calculated from the time histories of all the experimental participants (15 young and 8 elderly), including those who had a maximum braking force of 100 N or more. On the other hand, the 100–300 N [N/s] rate (Fig. 10) was calculated from the time histories of fewer experimental participants than the 0–100 [N/s] (three young and four elderly in the user-selected and two young and one elderly in the instructed), because the experimental participants had a maximum braking force of 100 N or more.

In this study, by comparing two sitting postures (user-selected and instructed), it was shown experimentally that the step-over time was faster and the maximum braking force was stronger when the sitting posture was changed from the user-selected to the instructed in young and elderly individuals. The results suggest that the sitting posture can improve the performance of emergency braking.

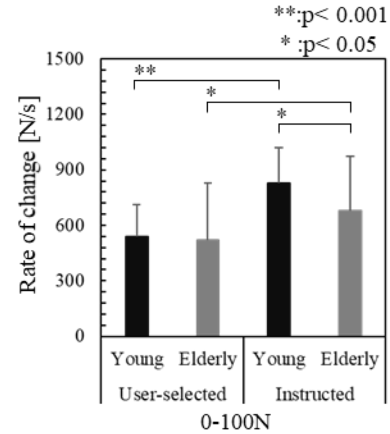

Fig.9 Rate of change in braking force

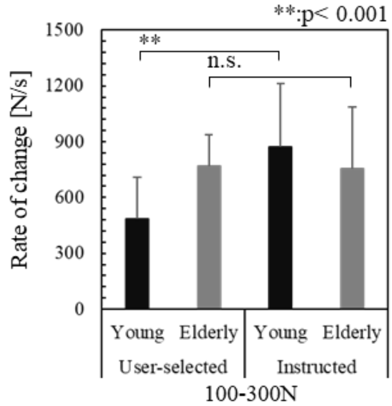

Fig.10 Rate of change in braking force

5. Conclusion

In this study, an experiment was conducted to clarify the effect of different sitting postures on emergency braking in young and elderly individuals. The results obtained in this study are as follows:

- The step-over time was faster in the instructed posture for both the young and elderly, and the young were faster in the instructed posture.
- The maximum braking force was stronger in the instructed posture for both the young and elderly. There was no difference in the braking force between the young and the elderly.
- These results suggest that the sitting posture can improve the performance of emergency braking.

In this experiment, two sitting postures (user-selected and instructed) were compared; however, it was thought that the posture can be improved further. Therefore, it will be necessary to analyse the mechanism of this result and determine the optimal leg posture. In the future, it will be necessary to study additional parameters, such as the seat-back angle and seat-slide position.

6. Acknowledgments

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