SAE International

2012-01-0073
Published 04/16/2012

doi:10.4271/2012-01-0073
saepcmech.saejournals.org

A Study on Design Factors of Gas Pedal Operation

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ABSTRACT

Lateral distance from the center of a driver's seating position to the gas and brake pedals is one of the main design factors that relates to the ease of stepping on the pedals from one and the other. It is important to keep a certain distance between the pedals to prevent erroneous operations or to reduce the driver's anxiety.

In this paper, we explain that the distance between the pedals is affected by the driver's seating height. In other words, if the driver sits lower, the accuracy of stepping on the pedals from the gas pedal to the brake pedal will increase compared to the higher seating position. In addition, we found out that providing auxiliary parts for the leg support enhances the accuracy of the pedal operations.

CITATION: Horiue, M., tomonori, O., Okiyama, H., Tanaka, Y. et al., "A Study on Design Factors of Gas Pedal Operation," *SAE Int. J. Passeng. Cars - Mech. Syst.* 5(1):2012, doi:10.4271/2012-01-0073.

INTRODUCTION

The layout between each device, such as a steering wheel and a gas pedal, and a driver's position needs to be optimally designed in order for the driver to be able to operate or control the vehicle at will. In particular, the operation of stepping on the pedals from the gas pedal to the brake pedal should be safe, precise and comfortable among such devices. It is vital to keep a certain distance from the driver's seating position to the pedals mentioned above to prevent erroneous operations or to reduce the driver's anxiety when he/she operates them.

As one of the brake operation studies, Wu et al. previously examined and measured drivers' operation and behavior characteristics in a car when they faced to an emergency situation, such as they needed to hit the brake hard to avoid a collision. Their report clarified the relationship among the leg muscles' activity, the reaction time until the drivers applied the brake and the brake operation time [1]. Yang et al. investigated the reaction time to apply the brake in an emergency situation base on one layout of the gas and the brake pedals [2]. However, they did not examine the effect of the gas and brake pedals' position changes. On the other hand, many studies have focused on the pedal layout and driver's foot movements between the pedals. Ronald et al. measured the time of the foot movements, changing a brake pedal to a gas into three longitudinal positions in combination with two lateral ones [3]. As the result, the case in which a brake pedal was placed closer to a driver than a gas needed the longest time for him/her to react. These studies discussed on the dimensions between pedals, but did not touch their relation to driver's seating position.

This report presents that the ease of pedal operation is influenced by the lateral layout between the pedals and a driver and by his/her seating height. In comparison with the higher seating position, the lower seating position provides more accurate pedal operations when stepping on the pedals from the gas pedal to the brake pedal. We also demonstrate that the auxiliary parts to support a leg help a driver to accurately move his/her foot between the pedals.

METHOD

A mock-up consisted of two pedals, a foot-rest and a seat was used in this study as shown in Fig.1. Each component is adjustable to any position and any angle. Pedal operation force is also adjustable by adding springs and weights to the mock-up.

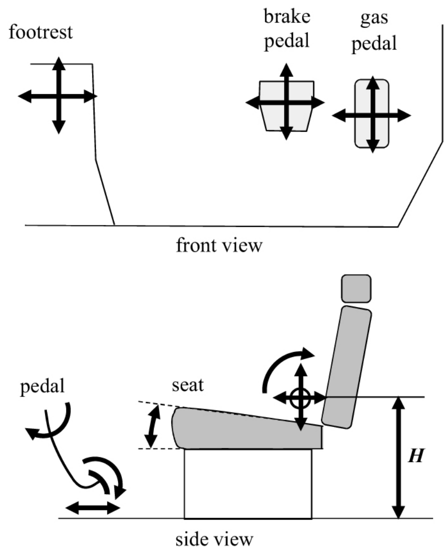

Figure 1. The mock-up used in this study

(1). Effect of the Seating Height

We used two seating height ***H*** conditions, at 145mm and 260mm. The lateral distance ***d*** from the center of the driver's seating position to the left margin of the gas pedal was set at 60mm, 80mm, 100mm, 120mm and 150mm for the each seating height. The distance between the gas pedal and the brake pedal was maintained at 70mm (Fig.2).

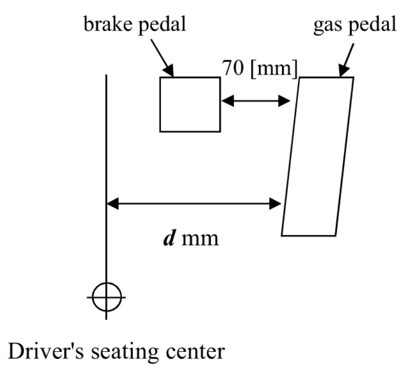

Figure 2. The pedal layout condition

Ten Japanese participants were recruited with informed consent for the study. Their height range was between 1500mm and 1920mm and the age range was between 26 to 62 years. They were asked to move their foot from the gas pedal to the brake pedal as fast as they can and press the brake pedal down as if they made a hard stop to avoid a collision. They were also instructed to step on the center of the brake pedal. Five trials were provided for each condition. The gap ***e*** between the center of the brake pedal and the center of the re-stepped foot was recorded as an indicator of operation accuracy (Fig.3). The participants also conducted a subjective evaluation regarding the ease of the pedal operation in five scales, which is described in Fig.4.

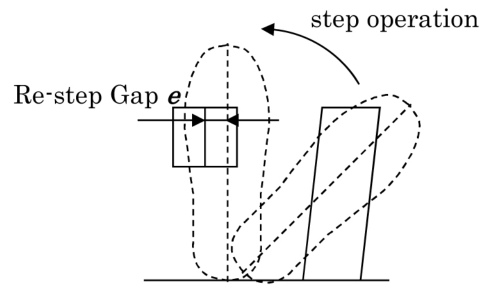

Figure 3. The definition of the re-stepped gap e

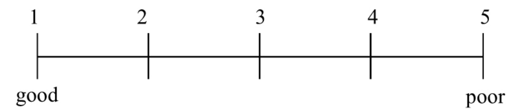

Figure 4. The evaluation scale for the ease of operation

(2). Effect of the Auxiliary Parts

As a study condition, the seating height ***H*** was set at 145mm. Other than that, the study conditions were the same as those described in 2-(1). The participants were asked to adjust the amount and the location of the leg supports to make their gas pedal operation comfortable. The leg supports used in this study were foam pads and metal plates to support a thigh and knee, respectively. The pad thickness and the plate position were determined by the participants base on their preference.

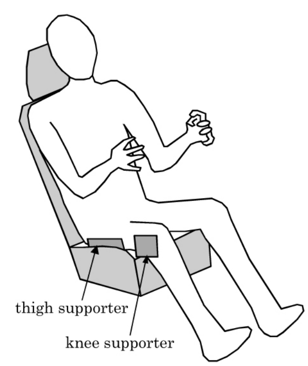

Figure 5. Supporters for thigh and knee

RESULT

(1). Effect of Seating Height

We determined the averages of the ten participants' re-stepped gap ***e*** at (***H***, ***d***) = (260, 150) as 0. Based on the point, Fig.6 shows that the normalized values of the re-stepped gap ***e*** for the each height is shown according to ***d***, the distance between the center of the driver's seating position and the edge of the gas pedal. In most of the cases, when the distance

d is getting close, the re-stepped gap e becomes bigger. And if the seating height is lower, then the ***e*** becomes smaller.

The averages of participants' subjective evaluation ratings at (***H***, ***d***) = (260, 150) was set as 3 and the normalized data is presented based on the point in Fig.7. The graph shows that when the distance ***d*** gets wider, the subjective evaluation rate becomes better. We can also see that the subjective rating becomes better for the lower seating height. Thus, even though the distance ***d*** is at 110mm, the lower seating height (145mm) can obtain the same level of the subjective rating as the higher seating height when the distance ***d*** is at 150mm.

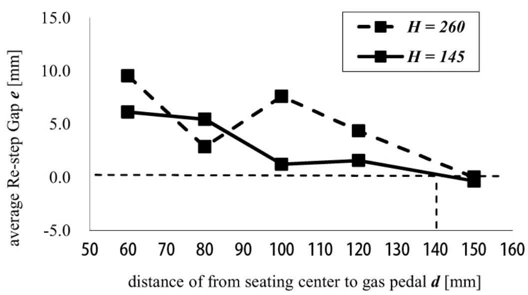

Figure 6. The relationship between e and d in the two seating height

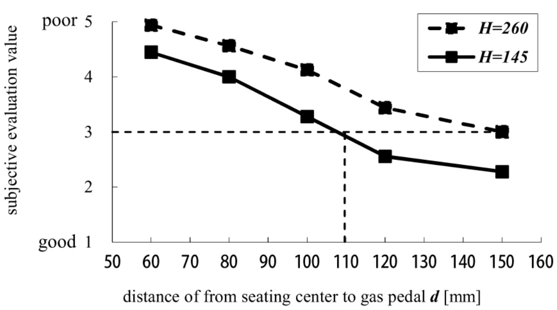

Figure 7. The relationship between subjective evaluation rating and d in the two seating height

(2). Effect of the Auxiliary Parts

The averages of ten participants' re-stepped gap e normalized in the same way as 3-(1) and they are provided according to d in Fig.8. The graph shows four different supporting conditions: without any supporting parts, only with a thigh support, only with a knee support and with both supports. The seating height was maintained at the lower position, 145mm, for any case. The study results show that the re-stepped gap e becomes smaller when the participants have leg supports. With the supports the seating height 145mm position can obtain the same re-stepped gap e result when the d was 150mm and the seating height was 260mm in Fig.6.

The averages of participants' subjective evaluation ratings for the effects of the leg supports were normalized in the same way as 3-(1) and they are shown in Fig.9. Here as we can see, the subjective evaluation rating becomes better when ***d*** is 100mm or smaller with any supports.

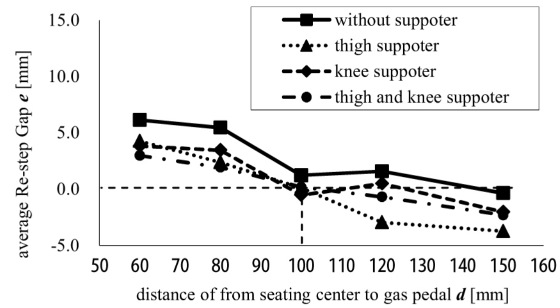

Figure 8. The relationship between e and d in each supporter's condition

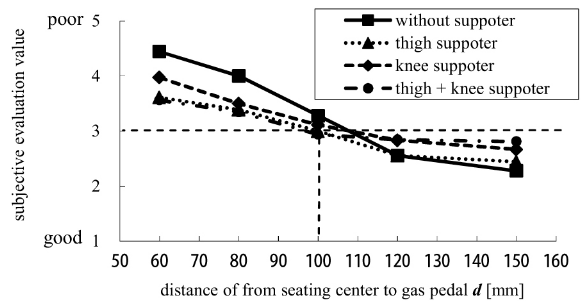

Figure 9. The relationship between subjective evaluation rating and d in each supporter's condition

DISCUSSION

(1). Effect of the Lateral Pedal Position

In this section, we discuss the reason why the re-stepped gap e becomes greater as the lateral distance d becomes smaller. First, as the distance d becomes smaller, the right heel moves toward the left and the right leg points to the left. Then, as far as the whole body keeps facing to the right front, the adducent muscles around the major trochanter or the hip joint are contracted more than those in its neutral position. As a result, the passive resistance around the hip joint increases. This generates a counter force against the leg inversion to move a driver's foot from the gas pedal to the brake pedal. Eventually, the foot center does not reach enough to the center of the brake pedal. In such a condition, the participants have a very difficult time to operate the pedals.

(2). Effect of Seating Height

We investigated the relationship between the seat cushion angle and the seating height (Fig.10). The seat cushion angle tends to be greater as the seat height becomes lower in order to maintain a comfortable hip angle. However, the relationship is not always linear and the cushion angle's change rate for a very low seat is quite small. Then, the driver's knee angle becomes greater.

Next, we examine a movement which a driver moves his/her foot from the gas pedal to the brake pedal without leaving his/her heel from the floor. This movement is provided by a rotation motion occurred around the line which connects the hip joint and the heel. In this system, we can explain the mechanic of the toe movements by the combination of the two types of the thigh movements around the hip joint. The first one is abduction-adduction or planar swing. The second one is internal-external rotation or axial rotation. The degree of how much those two factors involve to move a driver's foot between the pedals is deeply related to and changed by the seating height which causes the change of the driver's knee angle. In other word, the toe movements are mainly generated by the swing motion on the higher seat position and by the axial rotation on the lower seat (Fig.11).

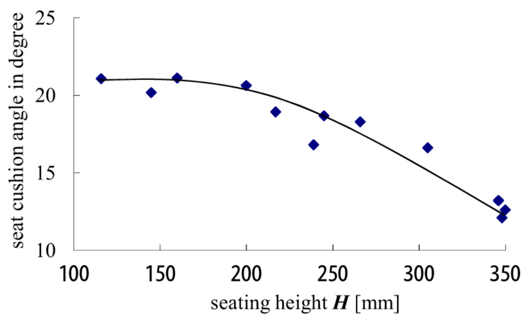

Figure 10. The relationship between seat cushion angle and H for passenger cars in stock

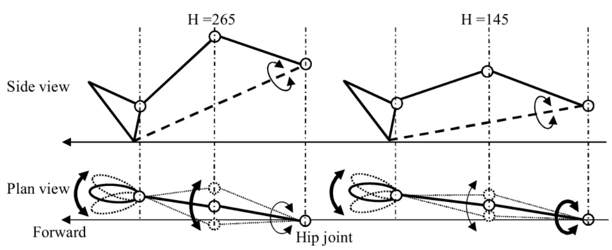

Figure 11. The contribution to the eventual toe movement by two types of movement system according to the two seating height

We study more about the point discussed above with a model described with the rigid link, which represents the lower extremities, in Fig.12. This model consists of two links and seven joints. The degree of rotation freedom for each joint is three at the hip joint, three at the heel and one at the knee. We decide that the heel does not move and the three joint angles, $\boldsymbol{q}_5$, $\boldsymbol{q}_6$, and $\boldsymbol{q}_7$, are determined by only the heel and the knee positions. The toe movement has a proportional relation to the rotation angle around the line that connects the heel and the hip joint or the rotation angle $\boldsymbol{\theta}$ of the whole leg system. Now by using a simulation, we figure out how much the hip joint angles $\boldsymbol{q}_2$ and $\boldsymbol{q}_3$ contribute to the rotation angle $\boldsymbol{\theta}$, which represents the toe movement, at the two different seating heights. The knee angle $\boldsymbol{q}_4$ is set as 90 degree for the higher seat and 130 degree for the lower seat. The hip angle $\boldsymbol{q}_1$ is set free (Table 1).

The computed results are presented in Fig. 13. The horizontal axis describes $\boldsymbol{\theta}$ and the vertical axis is the joint angle, $\boldsymbol{q_n}$. Here, we decide that each joint angle in the standard posture that the heel point, the knee point and the center of the hip joint are on the same plane which is parallel to the median plane is described as zero. The bold line shows the abduction-adduction, and the thin line describes the internal-external rotation. The dashed line is the 90 degree of the knee angle at the higher seat and the solid line indicates the 130 degree of the knee angle at the lower seat position. Table 2 shows the tolerance of each movement which is a premise for the computation. They are expressed as the dotted line in the figure.

As we can see in the figure, the solid line rotates in a clockwise direction in comparison to the dashed line. This means that the internal-external has more influence on the toe movements at the lower seat condition. In addition, the whole leg system rotates up to 33 degree because the thigh moves up to 45 degree, which is the upper tolerance of the internal, when the knee angle is 130 degree. However, it rotates only up to 25 degree even though the thigh moves up to 20 degree, which is the upper tolerance of the adduction, when the knee angle is 90 degree. In this manner, the rotation angle of the whole leg system becomes wider as the knee angle becomes greater. This generates greater toe movements. As a consequence, we believe if the seat height is lower, the driver can easily move his/her foot between the pedals and the re-steeped gap e becomes smaller.

Table 1. The variables used for computation

variable	joint
q1	Hip flexion and extension
q2	Hip adduction and abduction
q3	Hip internal and external rotation
q4	knee flexion and extension
q5	heel flexion and extension
q6	heel adduction and abduction
q7	heel internal and external rotation

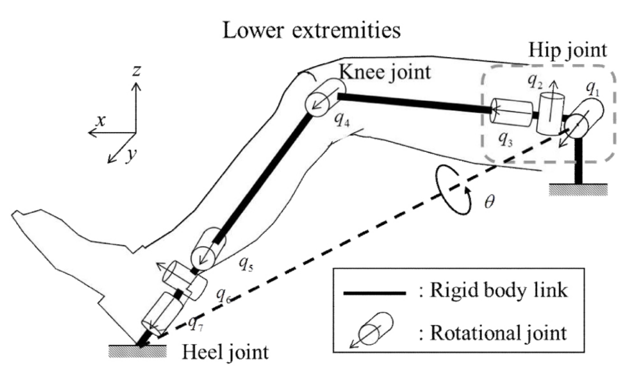

Figure 12. The rigid link model for computation

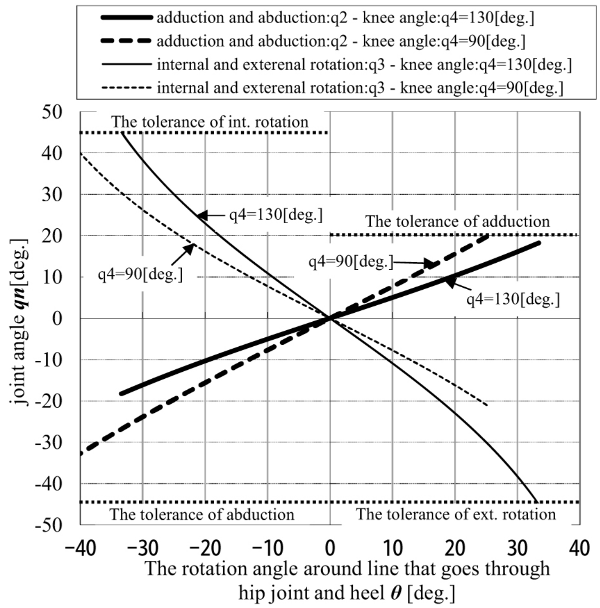

Figure 13. Each joint's rotation angle according to the two seating height

Table 2. The tolerance of each movement angle

Type of movement	The tolerance of movement angle
inward swing	20 deg.
outward swing	45 deg.
internal rotation	45 deg.
external rotation	45 deg.

From the dynamical point of view, changes of the inertia moment due to the knee stretch should be taken into account. We point out that the rotation radius around the line that connects the hip joint and the heel becomes smaller according to stretching the knee. This makes the inertia moment decrease and as a result the leg movement gets easier.

Further, we argue on the toe movement trajectory from the dynamical viewpoint. Minimum jerk models have been proposed for the reaching movement between two points with no constraint [6, 7, 8]. The foot movement dealt in this paper is the same sort of movement as the one from a gas pedal to a brake. Accordingly, the toe velocity curve during the movement is thought to form approximate “bell shape”. The fact is, however, the velocity is decreased to balance with a return force from brake as soon as the toe touches on the pedal. Accordingly, the velocity curve in the best practice is thought to form not a symmetric bell shape but an asymmetric one with a sudden drop just before the end of the movement. The argument is to be continued hereafter, since we do not have measurement data yet.

(3). Tendency of Personal Variation by Seating Height

The participants' lateral heel positions taking the brake pedal center as zero are shown according to their stature in horizontal axis and for each seat height (Fig.14). We found that the short height participants tend to locate their heel close to the gas pedal when they sit on the lower seat. The reasons for the tendency are as follows. As we previously mentioned, the internal rotation to step on the brake pedal becomes easier when sitting on the lower seat. This allows them to place their heel closer to the gas pedal as they need. At the time, the shorter drivers place their heel closer to the gas pedal to compensate their small foot size.

On the other hand, for the higher seat, we found apparently large variation for the heel positions, but do not find the tendency of heel position by stature.

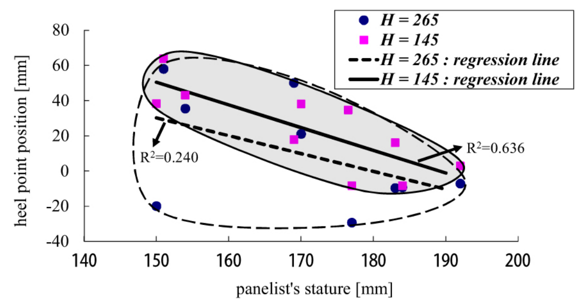

Figure 14. The relationship between stature and heel position for the two seating height

(4). Effect of Supporter

The re-stepped Gap ***e*** improves when auxiliary parts to support legs are used. The mechanisms are as follows. At the initial driving posture when a driver's foot is on the gas pedal, his/her leg usually stays in external rotation position to some extent with the thigh on the seat side bolster. However, when the leg supports are applied, the leg initial position gets closer to its neutral one. This initial position's difference with the supporter is thought to help reducing the necessary travel of the thigh internal rotation for re-stepping from a gas pedal to a brake. This reduction of the travel mitigates driver's uneasiness.

CONCLUSION

In this paper, we showed that the relationship between the driver's seating center and the pedal layout of lateral direction is affected by the driver's seating height in terms of the ease of the pedal operation. We clarified the following points:

(1). The re-step gap and the load of the pedal operation increased when the pedals are located more leftward from the driver's seating center.

(2). The re-step gap and the ease of re-stepping operation from a gas pedal to a brake improve as the seating height becomes lower. The reasons for (1) and (2) are illustrated from the mechanical and dynamic viewpoints.

(3). The re-step gap and the uneasiness of re-stepping operation improve when supporting parts for the knee and thigh are provided.

For the future, we will study about evaluation methods based on the minimum jerk model by measuring the foot's trajectory to be able to evaluate the details of the re-stepping operation.

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