Proceeding of the IEEE
International Conference on Robotics and Biomimetics
Dali, China, December 2019

Verification of the Driver's Fatigue Accumulation Reduction Effect at the Long-time Driving by Back Support Position Change *

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***Abstract* - In this study, we investigated the driver's fatigue reduction effect at multiple support positions in order to reduce the driver's fatigue during long driving.**
We examined each posture change when supporting the lumbar at these multiple support positions.
Then, the long time driving experiments using a driving simulator were conducted to evaluate the driving fatigue.
Based on these results, we clarified the difference in fatigue reduction effect due to the difference in support position based on biological information and subjective evaluation.

Index Terms – Driver's fatigue , Long-time driving

I. INTRODUCTION

In order to realize safe and comfortable driving, it is one of the important issues to realize improvement of driving fatigue of the driver. However, there are various causes of driver fatigue during driving. Therefore, it is not easy to clarify the whole of driving fatigue. Hence, it is necessary to narrow down the elements to be examined. Various researches and developments have been conducted on the driver's fatigue during this long driving [(1)(2)]. The authors have been studying on drivers' physical fatigue during long driving. When driving for a long time, maintaining the same posture causes muscles to stiffen, blood circulation worsens, and fatigue accumulates. Based on that, we used objective evaluation of driving fatigue using finger plethysmogram and increase in blood lactic acid level, which are driver's vital information, and subjective fatigue evaluation using questionnaire. And we showed that fatigue accumulation reduction during driving can be realized by giving a driver a posture change using a back support mechanism regularly [(3), (4)]. Their study used the position variable support mechanism, so they were able to support the preferred position of each subject. However, the seat with a fixed support position was used [(5)(6)]. Therefore, the result that the fatigue accumulation reduction effect for each driver is different[(6)] was confirmed from these results. Hence, we thought that it is necessary to verify again about the fatigue accumulation reduction effect to the back support position. The range of motion of the spine is wide. When the driver's body is supported by the support device during driving, the posture can be easily changed by supporting the lumbar of the driver.

In this paper, we investigate the driver's posture change and fatigue reduction effect when the back support position is changed between the first vertebra and fifth lumbar vertebra, and aimed to verify their relationship.

II. POSTURE CHANGE MEASUREMENT AT DRIVER'S SEAT

A. Equipment configuration of sitting posture measurement experiment

The authors have used lumbar support as a back support mechanism in previous studies [(3)(5)]. In this paper, we use an air-cell support (abbreviated below as air-cell), which has been confirmed to have the equivalent fatigue accumulation reduction effect [(6)]. The air-cell can be mounted on the seat back of the driver's seat easily, and the back support position can be changed to any vertical position. The air-cell is inflated by a manual pump and supports the driver's back. To investigate the driver's posture change at each support position, the measurement experiment of the posture was carried out. A camera with 24 million pixels was placed at a distance of 3 m from the subject side for measurement of posture change. The installation position of the camera was determined to be 0.2 mm per pixel.

B. Experimental condition of sitting posture measurement

The back support in this experiment is the amount of pressing the air-cell pump 10 times. The subjects are two men in their twenties. The subject A is 30 mm taller than the subject B. As shown in Fig. 1, each support position were four patterns supporting 90 mm, 120 mm, 150 mm, and 180 mm (hereinafter abbreviated as B90, B120, B150, and B180) above SRP. By adding this and the condition that the air-cell was not inflated, five experimental patterns were prepared. The order of them was random. The measurement procedure is shown below. First, the air-cell to height is set. And we shoot while the air-cell is not driven. The operator inflates the air cell and takes a picture. Furthermore, the air-cell is returned to

* This work is partially supported by NSF Grant #2003168 to H. Simpson and CNSF Grant #9972988 to M. King.

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the state where the air has been removed, and imaging is performed. This process was performed three times.

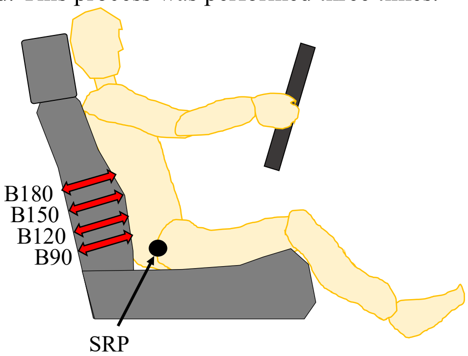


Fig. 1 Support positions by air-cell

C. Posture measurement analysis method

As shown in Fig. 2, the measurement points for posture changes were based on the subject's iliac bones, with 12 points on the side of the body (one iliac bone, nine trunks, two lower limbs). The thoracic spine parts from the point A to the point G. The lumbar part is from the point H to the point J. In order to analyze the posture change, the position of each point is obtained from the images. Then, the position of each point is converted from the pixel amount [pixel] to the actual length [mm]. The body posture change result when the air cell is driven matches the posture when the air cell is not driven with reference to the point K. The movement amount between each measurement point was defined as the amount of change in posture when the air-cell was used at each support position.

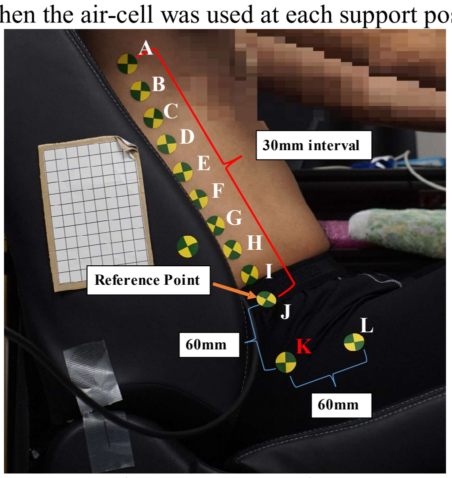
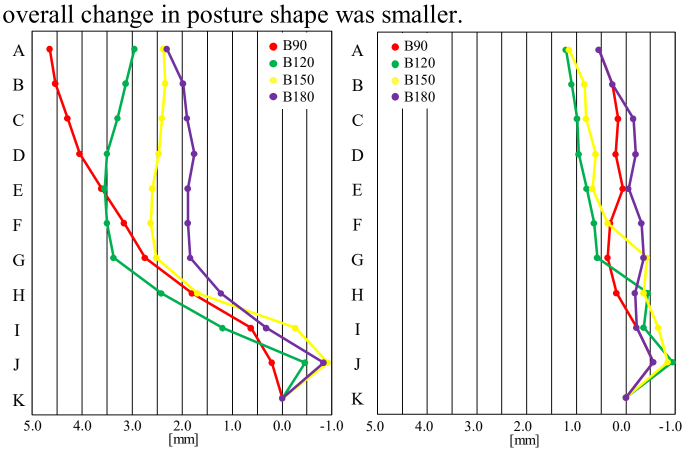


Fig. 2 Measurement points

D. Posture change measurement result

The amount of posture change was calculated. Fig. 3 shows the results of the calculated posture change. The vertical axis indicates the measurement position in the height direction, and the horizontal axis indicates the amount of change [mm] in the front-rear direction of the measurement point. Fig.3(a) shows the results of the subject A and Fig.3(b) shows the results of the subject B. In each figure, it shows the posture change when each position is supported, the red line shows B90, the green line shows B120, the yellow line shows B150, the purple line shows B180. In the case of the subject A, there is the 3rd lumbar spine near the point I. In the case of the subject B, there is the 3rd lumbar spine near the point J.

From the posture change measurement results, in the subject A, at points above the point G which is the border between the thoracic and lumbar vertebrae, the posture only moves backward without any change in the posture except for B90 which has largely lost the posture, and the lumbar spine becomes the shape change was confirmed below the point G. The difference between the change in points G and J is defined as the amount of change in posture shape. It was found that B120 and B150 were larger than B180, except for B90. On the other hand, the subject B similarly moved backward only at the point G or more, which is the boundary between the thoracic and lumbar vertebrae, and no change in shape was observed. In addition, except for B90, B120 was the largest in change amounts of G point and J point, followed by B150 and B180 in that order, but compared with the subject A, the overall change in posture shape was smaller.



(a) Subject A (b) Subject B

Fig. 3 Posture change amount

III. OVERVIEW OF FATIGUE EVALUATION DURING LONG-TIME DRIVING EXPERIMENT

A. Structure of experimental equipment

Based on the results of the previous section, driving fatigue measurement experiments were conducted in a long-time driving using a driving simulator (DS). Fig.4 shows the configuration of the experimental apparatus. It consists of a large monitor in front of the driver, a steering, an accelerator, a brake, one car seat and a seat belt. The car seat is the same as it used for posture measurement experiment. The driving course used in this study was selected that has a lot of curves to prevent chronic driving that tends to occur during long-time driving. The car that the subject drove was selected to be similar to the small car that the subject usually drives. For objective fatigue assessment, fingertip plethysmogram and blood lactate levels were used. BACS Advance was used for fingertip volume pulse wave measurement. Blood lactate levels of subjects were measured before and after the experiment.

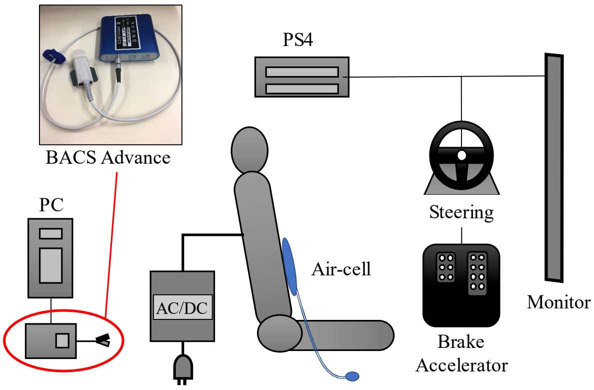


Fig. 4 The experimental system

B. Experimental conditions

In our study, air conditioner was controlled based on a thermometer and a hygrometer so that the experimental environment was almost the same. In addition, biometric information is easily affected by daily life rhythms (time for sleeping, waking up, eating, etc.). For this reason, subjects were required to make their time from the day before the experiment the same as possible. Each subject started the experiment at the same time of day. Fatigue from long-time driving experiments adversely affects the biological information of the subject the next day. Therefore, the experiment was carried out at intervals of more than one day. The experimental time is 90 minutes. The support device was driven after 15 minutes from the start of the experiment, based on the authors' previous research results. In the experiment, the air-cell is switched on and off every 15 minutes. The 'ON' state means that the air-cell is filled with air, and the 'OFF' state means that the air-cell is empty. The support positions were the same as B90, B120, B150 and B180 in the posture measurement. Table Ⅰ summarizes the experimental patterns. The measurement was performed 5 times for each pattern.

TABLE I. ACTIVE TIMING OF AIR-CELL

Pattern	Position	Inflate timing
1	—	NOT use air-cell
2	B90	Switch 'ON' and 'OFF' every 15 minutes
3	B120	
4	B150	
5	B180	

C. Driving fatigue evaluation method

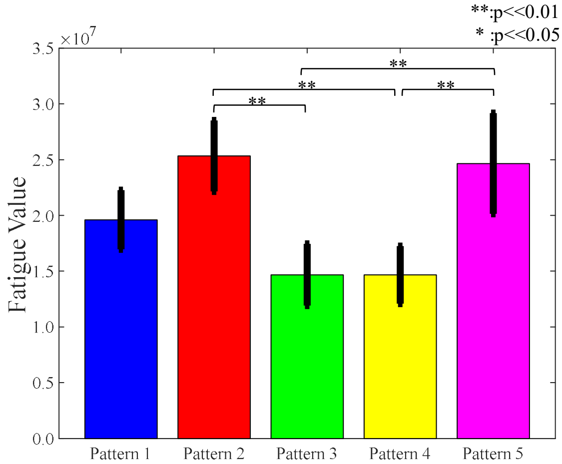
In this study, we evaluate the driving fatigue during long-time driving from both objective and subjective evaluations. As in the previous study, the objective evaluation consists of the pulse muscle fatigue curve method based on the fingertip volume pulse wave fatigue assessment method [7] and the blood lactic level proposed [8]. The fatigue during driving is evaluated by measuring the two methods. Fingertip plethysmography is easily affected by body movements such as hand movement during measurement. Therefore, we decided to set a measuring device on the elbow rest and always place the left hand on the elbow rest. The fingertip volume pulse wave is measured by pinching the tip of the middle finger into the device. For this reason, the steering operation was performed only with the right hand. During the experiment, subjects were allowed to sit back and change their own posture within the range that did not affect the measurement of the fingertip volume pulse wave according to the actual driving situation. In order to suppress fluctuations in blood lactic acid levels, subjects were allowed to stand in a resting state until the subject sat on the driving seat before the experiment began.

IV. EXPERIMENTAL RESULT

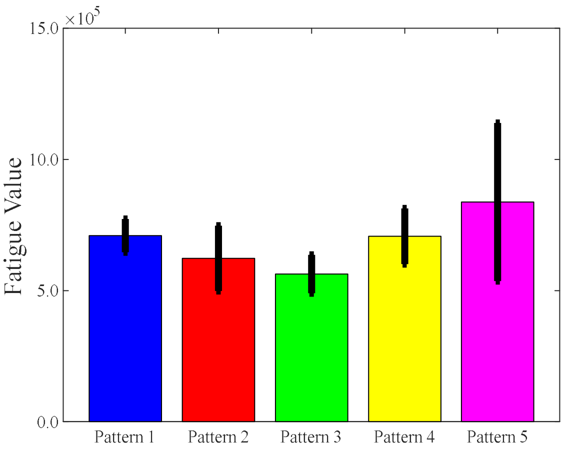
A. Objective fatigue evaluation result by pulse wave muscle fatigue curve

The pulse wave muscle fatigue curve was derived from the measurement results using the method described in section III-C. Fig. 5 shows the results of averaging the final values of the pulse muscle fatigue curves obtained in each experimental pattern. Fig.5(a) is the result of the subject A, Fig.5(b) is the result of the subject B. The vertical axis shows physical fatigue, and the horizontal axis shows the experimental pattern. Each bar in the graph shows the average value of the final value of the pulse muscle fatigue curve. The blue bar is pattern 1, the red bar is pattern 2, the green bar is pattern 3, the yellow bar is pattern 4 and the purple bar is pattern 5. In order to evaluate the significant difference of the final value of 90 minutes of the pulse wave fatigue curve, a significant difference test by multiple comparison is performed. Bonferroni's method was used for multiple comparisons. The black vertical bar in the bar graph is an error bar indicating the standard deviation. * Indicates a significant level, * indicates a significant difference of 5% level, and ** indicates a significant difference of 1% level.

From the results, in the subject A, a significant difference of 1% level was obtained for patterns 2 and 5 in both patterns 3 and 4, but not for pattern 1. However, as a result of performing a significance test for the other patterns alone with reference to pattern 1, a significant difference of 5% was obtained for both patterns 3 and 4 with respect to pattern 1, and the fatigue accumulation reduction effect was It has been confirmed. On the other hand, the subject B did not obtain a significant difference in the significance test of all patterns. However, as a result of performing a single significant test on other patterns with reference to pattern 1, a significant tendency was confirmed in pattern 3 with respect to pattern 1, and the fatigue accumulation reducing effect was confirmed.



(a) Subject A



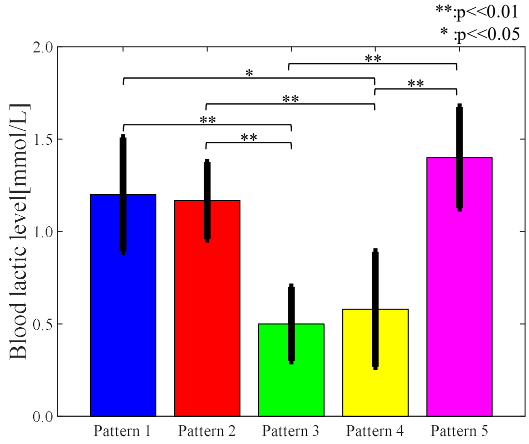
(b) Subject B

Fig. 5 Significant difference test result

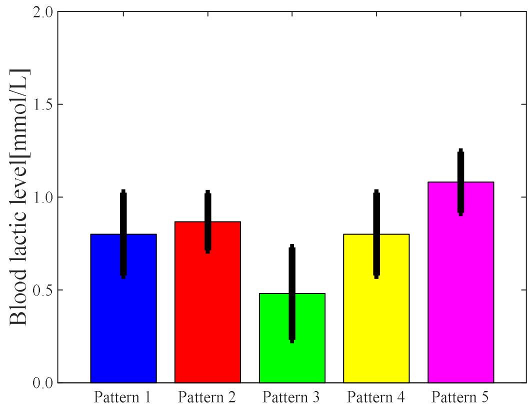
B. Objective fatigue evaluation result by blood lactic level increase amount

The amount of increase in blood lactate was derived by the method described in section III-C. Measurements were made 5 times between each experimental pattern for each subject. For each experimental pattern, a significant difference test was performed by means of multiple comparisons for the averaged increase in blood lactate. Figure 6 shows the increase in blood lactate and the test results. The vertical axis shows the increase in blood lactate, and the horizontal axis shows each experimental pattern. Each bar in the graph represents the average increase in blood lactic acid levels. Blue bar is pattern 1, red bar is pattern 2, green bar is pattern 3, yellow bar is pattern 4 and purple the bar is pattern 5. The black vertical bar in the bar graph is an error bar indicating the standard deviation. * Indicates a significance level, * indicates a significant difference of 5% level, and ** indicates a significant difference of 1% level.

From the results, it was confirmed that the subject A had a fatigue accumulation reduction effect in both pattern 3 and pattern 4 with respect to pattern 1, and a significant difference of 1% level and 5% level was obtained respectively. In 2 and Pattern 5, the fatigue accumulation reduction effect could not be obtained. On the other hand, the subject B showed a tendency to reduce fatigue accumulation in pattern 3, but no significant difference was obtained. However, as a result of performing a single significant test on pattern 3 using pattern 1 as a reference, a significant tendency was confirmed, and an effect of reducing fatigue accumulation was confirmed.



(a) Subject A



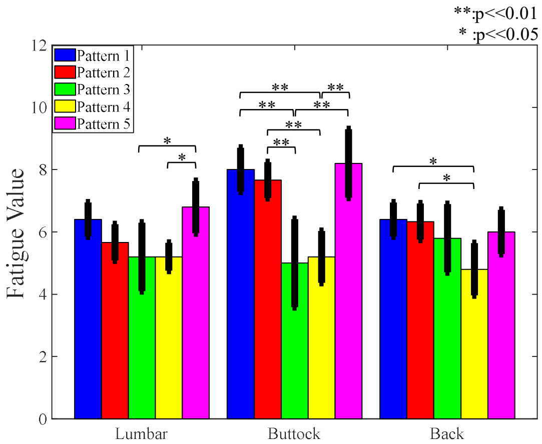
(b) Subject B

Fig. 6 Significant difference test result

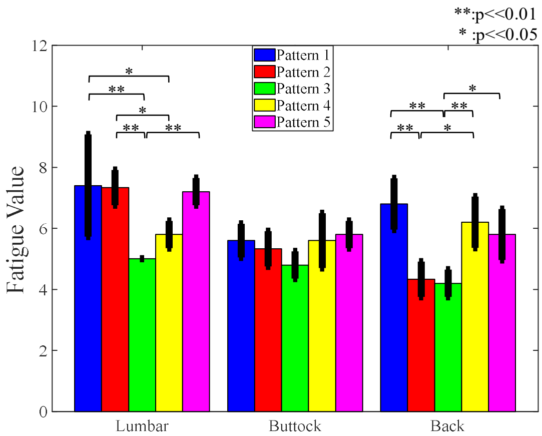
C. Subjective Fatigue Evaluation Results and Discussion

In the final fatigue value of each part obtained by the questionnaire, it was confirmed whether there was a significant difference in the fatigue value between the experimental patterns. Multiple comparisons were performed for each site, and significant differences between experimental patterns were evaluated. Figure 7 shows the mean and standard deviation of the final fatigue values of each part of each experimental pattern used for analysis of variance and multiple comparisons. Fig.7(a) shows the subject A and Fig.7 (b) shows the subject B's subjective evaluation results. The vertical axis represents the subjective fatigue value, and the horizontal axis represents the evaluation site. Each bar in the graph represents the average value of the final value of subjective evaluation. Blue bar is pattern 1, red bar is pattern 2, green bar is pattern 3, yellow bar is pattern 4 and purple the bar is pattern 5. The black vertical bar in the bar graph is an error bar indicating the standard deviation. * Indicates a significance level, * indicates a significant difference of 5% level, and ** indicates a significant difference of 1% level.

From the results, in the subject A, a significant difference of 1% was confirmed in both patterns 3 and 4 compared to pattern 1 in the buttocks, and only pattern 4 was significantly significant in the back of pattern 4 compared to pattern 1. The difference was confirmed. On the other hand, in the subject B, a significant difference of 1% level and 5% level was confirmed in both patterns 3 and 4 compared to pattern 1 in the waist, and pattern 2 and pattern 2 compared to pattern 1 in the back. In pattern 3, a significant difference of 1% level was confirmed.



(a) Subject A



(b) Subject B

Fig. 7 Subjective evaluation results

D. *Results and discussion*

In the subject A, the posture change was measured by changing the back support position, and the difference in posture was confirmed at each support position. In particular, the posture and shape change of the subject A was significant at the support positions of B120 and B150, that supported the third and fourth lumbar vertebrae. In patterns 3 and 4 that drive the support position, both objective and subjective fatigue evaluations were effective in reducing fatigue accumulation. Therefore, the feeling of fatigue is reduced at any of the three sites for which subjective fatigue assessment was performed, corresponding to the objective fatigue assessment results.

On the other hand, in the subject B, although the amount of posture change was smaller than the one of the subject A, the difference in posture was confirmed at each support position. In the case of the subject B, the posture change was significant at the B120 support position where the third lumbar spine was supported. In pattern 3, which drives this support position, both objective and subjective fatigue evaluation results showed a tendency to reduce fatigue accumulation. Therefore, as with the subject A, the driving fatigue was reduced at any of the three parts for which subjective fatigue assessment was performed, corresponding to the objective fatigue assessment results.

From the above, in order to reduce fatigue accumulation by changing posture periodically, it is effective to reduce the accumulation of fatigue by giving a clear lumbar posture shape change.

V. Conclusion

In this paper, we confirmed how the driver's posture changes when the back support position is changed, and verified the relationship with the fatigue accumulation reduction effect during long-time driving. As a result, it was confirmed that when each subject supported the vicinity of the 3rd and 4th lumbar vertebrae, the posture shape change was larger than the others, and the fatigue accumulation reduction effect was obtained. This suggests that the driver's back support position is an important parameter for reducing fatigue accumulation.

In the future, we plan to change the parameters of the driver's posture and change the degree of contribution to the fatigue accumulation reduction effect.

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