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Minor Study

A Case Study of Decreased Right-foot Activity with the Use of a Cruise Control System

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This study aimed to assess the direct effect of a conventional cruise control (CC) on the driver's physical workload. TheA test car was a Toyota Prius hybrid vehicle. The test driving was conducted on a 280 km road section on the Tohoku and the Hachinohe expressways. Psychological variables to estimate the CC effect upon the driver's workload were the general arousal checklist (GACL), subjective tiredness at the ankle-heel part of the right foot, and its activity force. While the GACL result revealed no improved mood change with CC use, the activity force data indicated that the CC use resulted in a considerable reduction in right-foot activity to a force level less than car vibration, suggesting its usefulness in reducing the physical workload on the right foot. It was inferred, thus, that car vibration was mainly responsible for the accumulated foot fatigue. The effect of decreased activity force on the driver's workload, which it has thus far been difficult to grasp precisely, was examined in prolonged driving on real expressways.

Key words: cruise control, fatigue, prolonged driving

A broad computerization movement has made it possible to equip automobiles with electronic systems to control driving speed automatically, to assist the driver's steering to help keep the vehicle between lane markers, and that sort of thing. Considering that recent vehicles with such a value-added system are not simply conventional mechanical structures, it is important to review the relationship between drivers and cars (Tsukamoto, 2005). A driving system to assist in speed control has been considered particularly valuable in making prolonged driving easy and comfortable for drivers.

Among driving-support systems is the cruise control (CC), which is intended for use on express highways. This system frees a driver from accelerator adjustment and maintains a certain speed by computer control. A set speed can be changed manually; thus, with this system, accelerator operation is basically by hand instead of by foot. For drivers, not needing to adjust the accelerator means easier driving. Cruise control was further advanced and automated with adaptive cruise control (ACC). This system enables a car to be driven at a certain speed set by a driver, like the cruise control system; in addition, when the car in front reduces speed, ACC automatically reduces speed and follows the car in front at a set distance. When the car in front is gone, the ACC accelerates the car to the previously set speed. Because ACC can automatically harmonize a car with the traffic flow, it is assumed to support tireless, comfortable driving even for long hours. Bauer (2003) pointed out that ACC makes driving easier because the system liberates the driver from the mental workload task of continually monitoring

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driving speed, and enables easy and safe operation even when following a slow car.

In actuality, however, few studies mention the immediate effect of CC or ACC, though such systems can lead to smooth driving by allowing the driver to release the right foot from gas-pedal operation. Moreover, almost no psychological information is provided in automobile makers' data (e.g., Toyota Motor Corporation, 2004), such as the extent to which tiredness and mental workload are reduced and how safe the system is in driving a long distance for many hours, although caution items in handling are stated in detail. Furthermore, the user's manual provides only instructions in operation and a brief caution. It would be difficult for users to determine if this system is safe and makes driving easier, just by reading the manual. Instead, the restrictions mentioned in the caution items could lead the user to think it would be safer not to use the system. Thus, users cannot easily find the rationale to use the system, and they may not become motivated to use it. Actually, a JAF report of drivers' opinions on Advanced Safety Vehicle (ASV) (JAF, 2005) suggested that drivers had little interest in using ACC. The present study thus focused on CC instead of ACC, and examined its usefulness. It also focused on the direct effect on the driver's right-foot pedal operation because recent car models often incorporate CC as standard equipment and most drivers are familiar with it, judging from the JAF report.

Since the late 1990s, several studies on the relationship between CC (including ACC) and drivers' mental workload have been conducted in the field of traffic psychology. In most of these studies, either the mental workload or the freed cognitive and physical resources for a second task have been measured, with years of driving experience as a psychological variable. These studies have attempted to clarify the indirect effects of CC and ACC.

Stanton and Young (1998) reviewed three earlier studies on ACC and an Active Steering (AS) system, which is a traffic lane maintenance system. Results demonstrated that these systems reduced mental workload for a second task paradigm; thus, these systems seemed to reduce driving workload. Hoedemaeker and Brookhuis (1998), however, pointed out that when ACC was used, speed tended to increase excessively, the distance from the car in front became shorter, and the brake pedal tended to be strongly pressed. All of these actions were associated with behavioral adaptation by the driver. Therefore, when an automobile was equipped with such safety systems, unsafe behavior tended to occur. Also, one report revealed that the use of ACC alone did not decrease workload. Stanton et al. (2001) set up four automation levels (manual, ACC, AS, and ACC plus AS) as independent variables, and systematically compared them. Their results indicated that the workload with the use of ACC alone was the same as that with manual operation. Only the use of ACC plus AS affected workload.

The specific effect of ACC on drivers' mental workload has not been consistent among studies. As a possible cause of such discrepancy, Young and Stanton (2004) suggested that reduction of the driving workload is not perceived even when it occurs, due to the influence of the task demands of driving. Furthermore, they speculated that the task used in testing might not be suitable for grasping the adaptive nature of ACC use. Testing was conducted to verify these two hypotheses, and the results suggested that the discrepancy lay in the driving task. Since the constant-speed task with ACC was the same as one with standard CC, these researchers believed that the essential function of ACC could not be demonstrated with this task. Furthermore, Rudin-Brown and Parker (2004) pointed out the driver's trait aspect as a possible cause: the ACC effect was observed in persons who scored highly on a sensation-seeking scale.

Additionally, most studies were conducted using an automobile simulator, not actual driving. Even with a simulator, independent variables considering actual situations were used when their validity was studied (Stanton and Young, 1998). Still, it was difficult to cover all negative safety factors that occur on actual roads, and test subjects tended to participate in the experiment as if playing a game. Considering these points, it cannot be denied that simulators are second best in determining the effects of CC and ACC. Additionally, in most experiments, the driving duration was short: even for the study by Rudin-Brown and Parker, in which the driving duration was relatively long and actual cars were used, the duration was only 30 minutes. Considering convenience for test subjects, this duration is the maximum time setting. Forcing high-speed driving over many hours on test subjects is not realistically possible, but it is necessary to assess what affects driving workload, by repeatedly collecting data using actual cars, before observing the direct effect on drivers.

Thus far, most studies of the effects of CC and ACC on drivers have investigated drivers' mental workload, based on self-reported evidence. They have not addressed the changes that ACC or CC use produced in the drivers' right-foot activity. It is necessary to examine the cruise-system device's effectiveness in order to understand how the physical workload in the right foot changes with no gas-pedal operation. In this study, this experimenter repeatedly drove long distances on express highways and collected data on mood, subjective fatigue, and right-foot activity. The purpose of this study was to study how much CC use reduces the driver's right-foot activity and prevents right-foot fatigue.

METHOD

Participant

The subject was the author of this paper himself (H. T.), a male aged 63 years at the time of test driving, with 37 years of driving experience and no history of accidents. This experimenter drives a car an average daily distance of 20 km, mostly for commuting. Until March 2005, this experimenter drove on an express highway only a few times each year, and thus did not have much experience driving on express highways.

Test vehicle

The test vehicle was a Toyota Prius S (model type: ZA-NHW11) hybrid vehicle made in 2001, with a 1,500 cc displacement engine and an automatic transmission. The range of the constant-speed control was 40 km/h to 100 km/h, and the memory speed could be increased or decreased by 1.5 km/h for every operation of the manual CC switch.

Test driving course

A 280-km section between Fukuchi Parking Area (PA) on the Hachinohe expressway and Tsurusu PA on the Tohoku expressway was used. Shiwa Service Area (SA), near the center of the section, was the short break point of driving. These two expressways have different geographical conditions and traffic volumes. The 67.6-km Hachinohe expressway from Ashiro JCT to Hachinohe is more elevated than the Tohoku expressway from Ashiro and south. Furthermore, the traffic volume of the Tohoku expressway is much heavier (JH Tohoku, 2004). The main test driving period was five months (May 2005 to October 2005).

Psychological variables

To estimate the degree to which CC provides a pleasant feeling and reduces physical workload to the right foot in normal driving (ND), we used three devices: the general arousal checklist (GACL) to measure mood change, subjective estimation of tiredness at the ankle-heel part of the right foot, and an Actiwatch to measure its physical activity.

1) GACL: This scale was used to assess subjective feeling and arousal level, which we considered to be an auxiliary measure of mental workload during driving. Long-distance driving may serve to decrease feelings of tension as well as energy, causing tiredness. Also, it is partly associated with habitual feelings of driving. In GACL, visual

analog scales were used to evaluate the driver's mood at the start and end spots of the first-and second-half sessions by marking a 100-mm line at a point corresponding to the strength of feelings represented by 20 adjectives related to activity and arousal. Mood states depicted in this scale differed in accordance with the other two independent dimensions of energy arousal (energy-tiredness continuum) and tension (tension-calmness). The energy arousal dimension consisted of general activation (GA) and deactivation-sleep (D-SI), and the tension arousal dimension consisted of high activation (HA) and general deactivation (GD), with each of these four factors described by calculating the average of five related adjectives.

2) Rating of tiredness at the ankle-heel part of the right foot: Tiredness at the ankle-heel part of the right foot during driving was rated from 0 (no tiredness) to 100 (the strongest tiredness subjectively felt). This rating was conducted orally at the time of passing each interchange on the two expressways, and recorded by a sound recorder.

3) Right-foot activity: An Actiwatch (Mini-Mitter AW64[1]) was used to measure right-foot activity. This wristwatch-size (30 mm long × 28 mm wide) piezo-electric accelerometer with a physical movement sensor was simply fastened to the recording site. The movement of the right foot for gas-pedal operation was based on physical control functions capable of dynamic muscular movement in response to plantar flexion during acceleration by pressing on the pedal, and to dorsiflexion during speed reduction. A belt was used to fasten the Actiwatch to the transverse arch of the driver's right foot, to record the degree to which the accelerator operation was carried out. With epoch time set at 2 sec., activity data were stored on the integration of intensity, amount, and duration of movement accompanying gas-pedal operation, and car vibration during that time. To record car vibration only, an Actiwatch was attached to the dashboard just above the floor position of the gas pedal. For statistical data-processing, the epoch length originally recorded was changed to 1 minute to obtain new data, with values added up in 30 consecutive 2-sec epochs.

Procedures

Test drives were taken up from Hachinohe to Sendai, and down from Sendai to Hachinohe, under the CC condition or the ND condition. Under the CC condition, the initial speed was set at 95 km/h. When it was judged safer to change the set speed due to traffic volume or a passing vehicle, the setting was changed manually, and the speed was slightly increased or decreased. When it was judged difficult to maintain safe driving at the initially set speed due to cutting-in by another vehicle or speed reduction by a forerunning car, the setting was cancelled, and ND was conducted until safety was secured. The target speed under the ND condition was 95 km/h. On the Hachinohe expressway, driving speed was changed to conform to the regulated legal maximum speed of 80 km/h.

RESULTS

Twenty-two test drives, with the drives up and down combined, were conducted between Hachinohe and Sendai, and data on sixteen drives were analyzed, with the ex-

[1] This acceleration-sensitive device has a solid-state memory that stores data on the number of movements per unit of time. In this study, gas-pedal activity counts for consecutive 2-sec periods were recorded. The Actiwatch collected data 32 times per second. These data, indicating the presence of any acceleration above a certain threshold, were stored in a buffer and then at the end of the epoch. Measurement of activity by the monitor was nonlinear. The watch integrated the area under that curve and reported the integration of the area. One count equaled 0.000175 G-Force (personal communication with Mini Mitter Company, Inc., 2001).

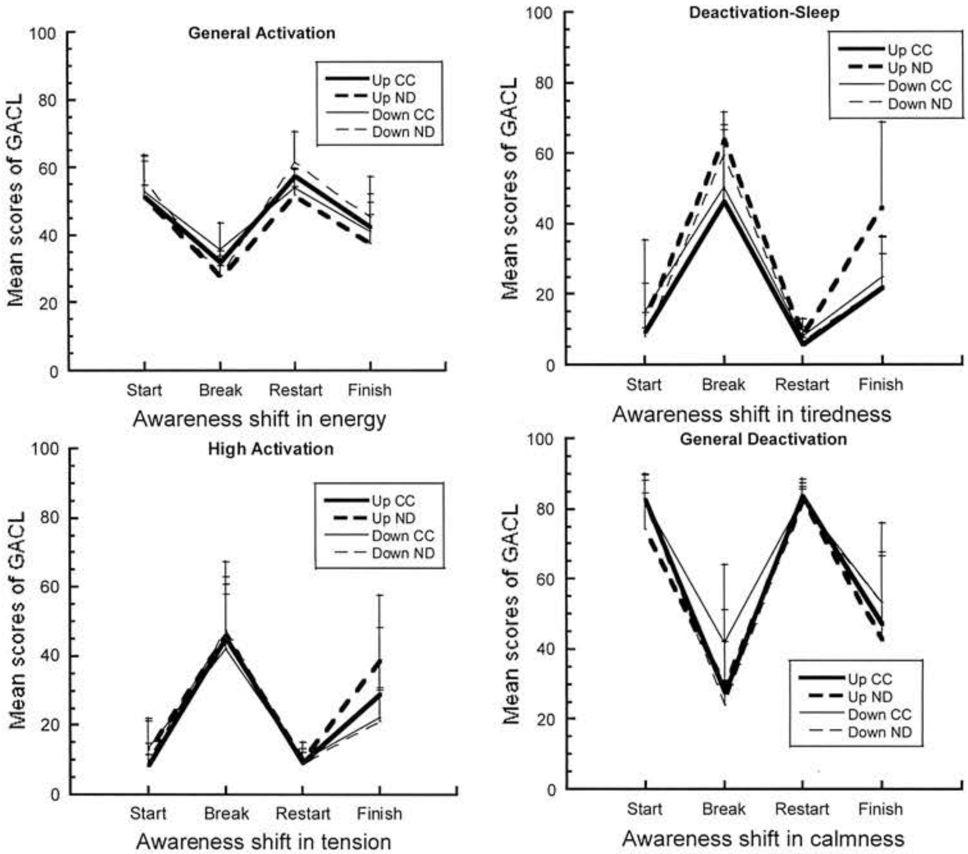

Figure 1 Mean values with corresponding standard deviations of start, break, restart, and finish points of driving in each of four GACL factors: general activation, deactivation-sleep, high activation, and general deactivation.

ception of those under extremely bad weather conditions and at night among all the test drives. Additionally, five control drives were conducted to record car vibration only, and the data on four of those drives were used.

The average times required for the 16 drives except for a short break between two sessions were 178.0 min ($n=9$, $sd=6.4$) in the up drive and 174.9 min ($n=7$, $sd=5.0$) in the down drive, with no difference between the two drive directions. Furthermore, no difference in required time was observed between driving styles of CC and ND (CC: 178.6 min, $n=8$, $sd=5.8$; ND: 174.6 min, $n=8$, $sd=5.6$).

1) GACL

Complete drive runs without any missing data on the GACL included five runs under both CC and ND conditions on the up drive, and four in the CC condition and five under the ND condition on the down drive. Mean scores for each of the four factors were calculated and used as raw scores for further analysis. No significant difference was observed in the scores for each factor between the up and down drives (Figure 1).

The result of the three-way ANOVA (drive style (2)×direction (2)×place (4)) indicated that the main effect of place was significant (GA: $F(3/4)=30.2$, $p<.01$; D-SI: $F(3/4)=33.9$, $p<.01$; HA: $F(3/4)=90.6$, $p<.01$; GD: $F(3/4)=85.7$, $p<.01$). The significant difference between the short break at midpoint and the restart from there implied that the break led to restoration to the mood level at the start. However, no significant difference occurred between the CC and ND conditions, or between the drive directions of up and down.

2) Fatigue at the ankle-heel part

Figure 2 presents the typical results of the ratings for the ankle-heel part of the right foot when the vehicle was passing interchanges. In this figure, a curve tending upward is a ND case of the up drive from Hachinohe to Sendai with a short break at Shiwa; the curve tending downward is an ND case of the down drive. Under the ND condition, the ratings increased as time passed, in driving from either place of departure in the up direction or the down direction. Although a short break at the midpoint led to the restoration to zero-level fatigue, the degree of fatigue increased extraordinarily in the second-half session of driving just after restart. However, the ratings were 20 or below under the CC condition.

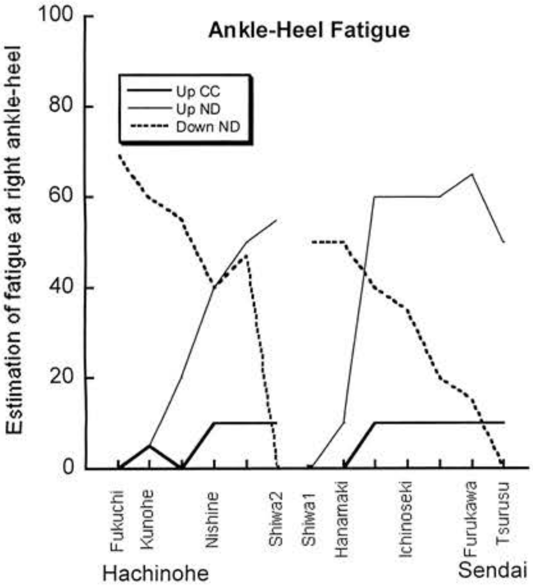

Figure 2 Typical samples of the ratings for the ankle-heel part of the right foot in the vehicle's passing of interchanges (Shiwa1 = restart at the up drive, Shiwa2 = restart at the down drive).

3) Activity measurement

Since no difference in activity was found between up and down drives, Actiwatch data were grouped for further analysis into two groups (first-half driving session from departure to Shiwa SA at the midpoint, and second-half session from Shiwa SA to the destination). Eighty minutes' data obtained in each of the two course sections were processed, with the exception of those just after the beginning of driving and immediately before arrival at the destination. Figure 3 depicts (a) the first-half session of driving and (b) the second-half session, in which three curves (CC, ND, and car vibration) are

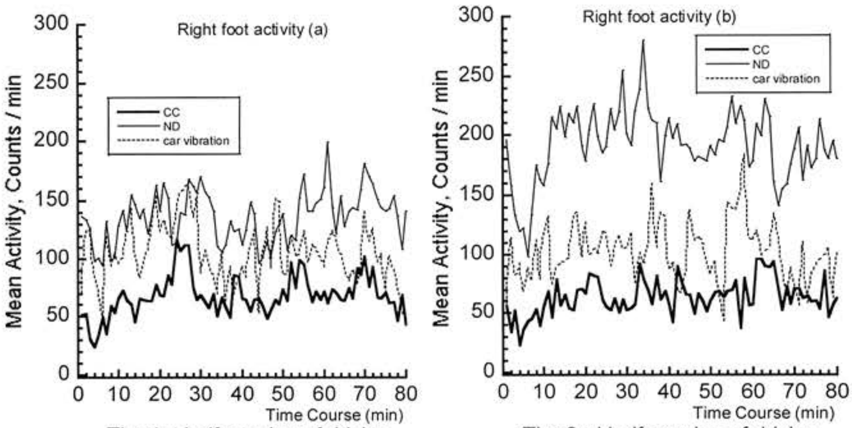

Figure 3 Time-series changes in activity of the right foot under CC and ND conditions, and car vibration (a = the first-half session of driving, b = the second-half session).

presented. In order to examine the effect of CC upon the right foot, the Actiwatch activity counts were subjected to a two-way ANOVA (drive style (3) × session (2)) for convenience. Results revealed a significant main effect of driving style ($F(2/474) = 721.1$, $p < .001$) and a significant main effect of session ($F(1/474) = 55.7$, $p < .001$). Furthermore, the interaction between driving style and session was significant ($F(2/474) = 85.5$, $p < .001$). Post-hoc testing of significant effects was conducted in each session, using Bonferroni's adjustment for multiple comparisons: a two-tailed α-level of .05 was used to determine statistical significance. All combinations of CC, ND, and car vibration in each session were significant, with the CC condition yielding the least activity force. The ND condition had the largest values. Furthermore, the results of the Wilcoxon test indicated that, in the ND condition, the activity force increased significantly in the second-half session ($Z = -7.7$, $p < .001$ (two-tailed)).

DISCUSSION

This report sought to examine the direct effect of CC on the driver's right-foot gas-pedal operation, by using an actual car on express highways. One limit to the assessment was that the data obtained were from this author himself. Thus, it will be necessary to analyze the driving of other participants and to conduct further research to accumulate more data. However, due to its nature, this type of research seems to be very limited, both inside and outside Japan. For example, using a simulator for such a study creates an unrealistic situation in which no other competing vehicles are on the short test course. Even when an actual car is used, the driving duration is generally very short. In contrast, real situations involve various factors, making it very difficult to grasp what brings about the target effect. Fortunately, express highways have much more controllable conditions than general roads (e.g., no signals and no sidewalks), and they meet some of the requirements for test driving. Of course, even when such highways are used, many general vehicles are often present; and if an accident occurs, lives can be threatened because of high-speed driving. Also, because vehicles are not perfectly reliable, participants cannot be recruited casually.

In the past several years, a surprising amount of information technology (IT) has been incorporated into automobiles, and research on this change now needs to be aggressively introduced in conventional traffic psychological studies. One mission of traffic psychology is to establish an environment that enables general users to have a sense of security as they enjoy the benefits of such advanced technology. This study focused on CC, which was the first system directed at reducing driver workload. With CC, it is impossible to drive at a set speed; as a result, speed reduction or increase by either manual switch operation or gas-pedal operation is required. Unlike ACC, CC does not have a radar mechanism to measure distance from a forerunning car; therefore, the driver must control that distance. In other words, its low driving-assistance level results in less dependence on the system than ACC use does. Young and Stanton (2004) found a negative result in reducing the driving load with CC. However, we have conducted a preliminary trial on real expressways to verify that the release of the gas pedal during long hours of driving does have some effect (Hatayama, 2006).

In the present study, twenty-two test drives were conducted, with a short break, between Hachinohe and Sendai. Each drive involved no difference between the time required for the up direction and that required for the down direction, and separate analyses were conducted for first-half and the second-half sessions.

While the GACL result indicated no improved mood change with CC use, the Actiwatch data indicated that CC use resulted in considerable reduction in right-foot activity, suggesting usefulness in decreasing the physical workload for the right foot. Interestingly enough, the level of this foot activity was less than the vibration level of the car itself. However, the level of right-foot activity under the ND condition was significantly higher than that under the CC condition or under car vibration. In addition, the level under ND rose significantly in the second-half session of driving. In prolonged ND driving of the second-half session, continuous gas-pedal operation, led to a steady increase of fatigue in the right foot. The higher level of ND activity in the second-half session was probably related to increased irrelevant performances, such as the release of the right foot from the gas pedal to deal with accumulated fatigue.

The decreased right-foot level of activity as a CC effect was less than the level of car vibration itself because drivers using CC tended move their right foot from the gas pedal to the floor in front of the driver's seat and to place the sole of their right foot on the floor. The level of foot activity was then less than the level of car vibration, due to the sole's absorption of the vibration, based on the anatomically sophisticated structure, plantar arches, of the foot such as the medial arch. With CC or ACC use, the effect of car vibration on the right foot was markedly reduced; thus, tension and fatigue in the right foot should be eased during prolonged driving, though CC or ACC did not directly reduce the level of mental workload or lighten mood (Hatayama, 2006). This study also indicated that car vibration was mainly responsible for foot fatigue during prolonged driving, as Taguchi (1998) pointed out with regard to driver's physical fatigue. Additionally, the significant increase in right-foot activity force during the second-half session of driving under the ND condition suggested that fatigue may be partly caused by sustained muscular activity accompanying gas-pedal operation over a long period of time.

The technology that can reduce the driver's physical workload may substitute an important part of driving performance. Further studies should clarify the ways that these advanced technologies should be used and how they may eventually contribute to vehicle safety. In addition, for elderly drivers, such technology may have more significance than for younger drivers, since the expansion of elderly drivers' behavior range is highly possible.

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