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# Detecting Driver Fatigue by Steering Wheel Grip Force

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***ABSTRACT***

*Driver fatigue is a major cause of fatal road accidents and has significant implications in road safety. In recent years, researchers have investigated steering wheel grip force as an alternative method to detect driver fatigue noninvasively and in real time. In this study, a fatigue detection system was developed by monitoring the grip force and changes in the grip force were measured while participants' engaged in an interactive simulated driving task. The study also measured the participants' subjective sleepiness to ensure the validity of measuring grip force. The results indicated that while participants engaged in a driving task, steering wheel grip force decreased and subjective sleepiness increased concurrently over time. The possible applications of the driver fatigue detection system by steering wheel grip force and future guidelines are discussed.*

***Key words**: Driver Fatigue, Force Sensor, Steering Wheel Grip Force, Subjective Sleepiness.*

## 1. INTRODUCTION

Drowsiness or fatigue while driving is a well-known risk factor for traffic accidents [1]-[6], and this factor has been shown to significantly decrease real driving performance during prolonged and monotonous driving [7]. According to The US National Highway Traffic Safety Administration (NHTSA), 100,000 vehicle crashes each year are the direct result of driver fatigue. These crashes resulted in approximately 1,550 deaths, 71,000 injuries and $12.5 billion in monetary losses [8].

Driver fatigue has numerous causes [9], each with a specific incidence and relationship to traffic accidents. The factors most commonly associated with driver fatigue are monotonous environments, duration of driving, sleep deprivation, chronic sleepiness and drug and alcohol use [10], [11]. In the past few decades, various studies have been conducted to measure driver fatigue for its prevention. Among the numerous ways to measure driver fatigue, most studies have used physiological, behavioral, and vehicle-based measures.

Physiological measures mostly employ electroencephalograms, heart-rate variability, and electrocardiograms [7]. Physiological measures have the advantages of objectivity and a high credibility for detecting driver fatigue compared with other methods. However, the data obtained using physiological measures can easily be corrupted by a driver's movement [12], and the measurement techniques cannot be used in actual driving situations, owing to their invasive measurement methods [13]. On the other hand, several other studies have been conducted to measure driver fatigue through noninvasive behavioral measures such as eye closure, head pose, facial expressions, and yawning [14]. Despite the advantages of their noninvasiveness, the problems with behavioral measures are that environmental factors such as the illumination, brightness, and road conditions influence the credibility and accuracy of measurement [15]. In addition to physiological and behavioral measurements, some researchers are trying to measure driver fatigue through steering-wheel movement and vehicle movement such as the standard deviation of the lane position [12]. However, measuring driver fatigue according to the vehicle movement is limited because the measurement values can be easily affected by external

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factors such as the geometric characteristics of roads and weather conditions [16].

In order to supplement the limitations of the aforementioned measures, some researchers have striven to detect driver fatigue through the steering-wheel grip force (e.g., [17]-[21]). According to Lin et al. (2007), the steering-wheel grip force is strongly correlated with other factors that are used to measure driver fatigue, such as the pulse wave [20]. Polychronopoulos et al. (2004) suggested that the grip force can be used with other measures such as eye movement [21]. Compared with other measures, the steering-wheel grip force has several advantages for detecting driver fatigue. Firstly, it does not interfere with measurement systems and can be used in actual driving situations owing to its noninvasive measurement method. Additionally, because it is not affected by illumination and the external environments, the measurement can be performed in both daytime and nighttime, thereby reducing the time constraints. Moreover, attaching a grip force sensor to a steering wheel costs less than other measures [18].

Despite the advantages of detecting driver fatigue using the grip force, few researchers have attempted to develop a measurement system and identify the validity of grip force. For example, Chieh et al. (2003) attempted to identify the starting point of fatigue by detecting the level of significant decrease in the grip force using a grip-force monitoring system [19]. Polychronopoulos et al. (2004), Baronti et al. (2009), and Lin et al. (2007) also developed driver fatigue detecting systems through a comprehensive multi-sensor driver-monitoring system that included the grip force [18], [20]-[21]. However, most previous studies focused on the development of measurement methods and did not verify the validity of the grip-force measure through empirical studies. Moreover, the experimental sessions of prior studies were too short to predict driver fatigue. For instance, in the study by Lin et al. (2007), the experimental sessions to measure the grip force were less than 5 min [20].

Therefore, the purpose of this study was to examine the grip force change while participants were engaged in an interactive driving simulation task. In addition, the participants' subjective sleepiness was measured and the relationship between grip force and subjective drowsiness was analyzed.

## 2. MATERIALS AND METHODS

### 2.1 Participants and Settings

Thirty-one adults participated this study (16 males, 15 females) and their average age was 24 (SD = 3.2). None of them had suffered from driving-related muscular skeletal diseases or been diagnosed with alcoholism or drug addiction. The study was performed in a laboratory that was equipped with a screen, projector, driving wheel and pedal, and computer for the driving simulation. The laboratory temperature was maintained around 24–26 °C in order to control environmental factors that can affect driver fatigue. The laboratory was kept dark to induce drowsiness. The laboratory comprised 2 rooms: in one room, the subjects participated in the experiment, and in the other room, a researcher monitored the experimental procedures.

### 2.2 Apparatus

A FSR-408 strip sensor was used in this study to measure the grip force (Fig. 1), and its sensitivity was 0.1–10.02 N. The sensor consisted of robust polymer thick film (PTF) devices that exhibit a decrease in resistance with increase in force applied to the surface of the sensor. In other words, the output voltage increased with increasing force with equation as follows: $V_{out} = R_M V + / R_M + R_{FSR}$. The length of an FSR-408 strip sensor was 622.3 mm, the width was 15 mm, and the thickness range was about 0.2–1.25 mm. The sensor was flexible, could be bent, and was easy to attach on a steering wheel and perform measurements because it was possible to do so even when pressure was only partially exerted on the sensor. The sensor was attached on the right side of the steering wheel.

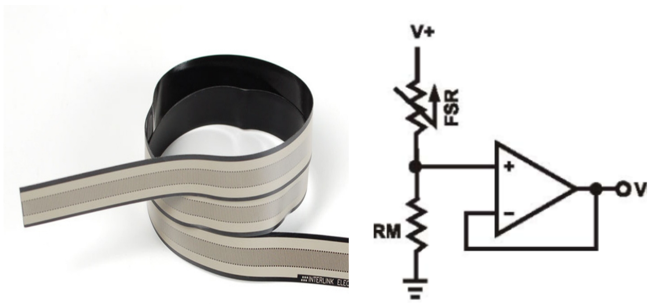


Fig. 1. FSR-408 strip sensor and its schematic

The participants operated an interactive driving simulation as their simulation task, using Euro Truck Simulator 2. Euro Truck Simulator 2 was also used for simulation tasks by Fagerlönn et al. (2012), and unlike other gaming simulations, it reflects the driving and road conditions realistically [22]. The simulator allowed the driving settings to be varied. In this study, the driving speed was limited to 60 km/h and most of the driving roads were set as straight to control the external factors. For the steering wheel and pedal, Logitech G27 Racing Wheel was used. The following is a diagram of the simulation screen and experimental-equipment installation.

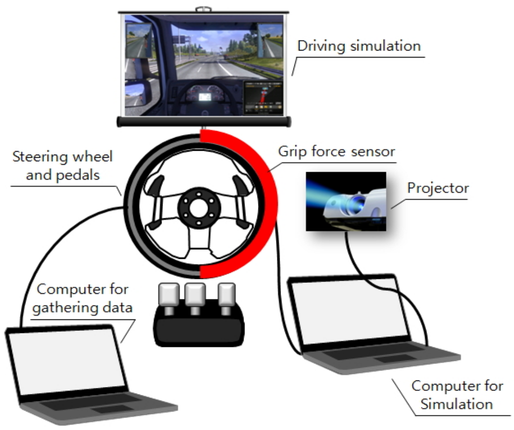


Fig. 2. Simulated driving task diagram

### 2.3 Procedures

The participants were requested to sleep less than 5 hours the day before the experiment in order to induce drowsiness. They were also requested not to consume alcohol and caffeine for 24 and 4 hours before the experiment, respectively. The experiment was conducted from 2pm to 4pm, the time of day when accidents due to drowsiness and fatigue are most common [23].

When the participants arrived at the laboratory, the researcher asked them whether they had followed the requirements and requested them to complete a demographics survey. Upon completion of the demographic survey, the researcher explained the purpose and experimental procedure of the study and asked the participants to sign an agreement form. Then, the researcher demonstrated the experimental task for 5 minutes and made the participants operate the task for 5 minutes as a practice. Before the experiment started, the researcher checked whether the laboratory's illumination and temperature were appropriate. After the experiment started, the participants operated the interactive driving simulation task for an hour. For the measurement credibility of the grip force, the participants were asked to grip the right part of the steering wheel where the sensor was attached. While the participants performed the task, pressure values were measured at one-second intervals, and they were automatically recorded to a program developed for this study.

In addition to the grip force, the subjective sleepiness was also measured in order to improve the validity of the measurements. The degree of subjective sleepiness was measured on a 7 point scale (1 point: not sleepy at all – 7 points: very sleepy). Every 10 min, the researcher entered the room where the participants were performing the task to ask them verbally about the degree of subjective sleepiness, and the participants answered with a number from 1 to 7. The measurement time for subjective sleepiness was less than 10 s.

## 3. RESULTS

### 3.1 Data Analysis

The grip force and the degree of subjective sleepiness were analyzed in 10 min intervals while the participants consecutively performed the task for an hour. For the data analysis, the average value of grip force of the last 30s in each 10 min interval was used. Regarding the subjective sleepiness, the score that was reported immediately after each 10 min interval was used for the analysis. Repeated measures ANOVA was used to verify the changes in the grip force over time. To control the individual variance of the participants, the first 30s of each participant's grip force during the experiment session were used as the covariate variable.

### 3.2 Grip Force and Subjective sleepiness

The averages and standard deviations of the grip force (Vout) and the subjective sleepiness over time are shown in Fig. 3. The results showed that the grip force tended to decrease over time. Specifically, the average Vout of the last 30s for the first 10min was 5.81 (SD = 3.26), 5.52 (SD = 2.80) for 20 min, 5.56 (SD = 2.76) for 30 min, 5.49 (SD = 2.37) for 40 min, 4.82 (SD = 1.54) for 50 min, and 4.75 (SD = 1.46) for 60 min.

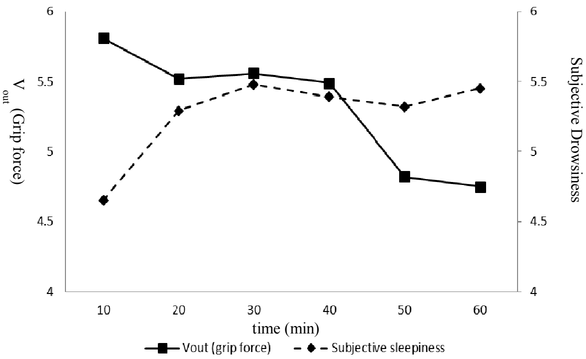


Fig. 3. Steering wheel grip force and degree of subjective sleepiness over time

Repeated measures ANOVA was used to compare the differences of the Vout values' changes over time. The sphericity assumption was tested using the Mauchly's test ($p > .05$) and the Greenhouse Geisser correction was applied where appropriate to correct for violations of sphericity. After the difference reached the significant level ($F$ (3.08, 89.31) = 13.08, $p < .001$), a post hoc test was used to examine the time slot exhibiting a significant difference in pressure (Table 1). The post hoc test revealed that there were no significant differences of the mean grip force from 10 to 40 min ($p > .05$). However, compared to the first 10 min, it significantly decreased after 50 min ($p < .001$).

Table 1. Results of Post hoc test for $V_{out}$ by time slot

| Comparison | | mean difference | *SE* | *P* |
|---|---|---|---|---|
| 10 min vs. | 20 min | .29 | .24 | .243 |
| | 30 min | .25 | .32 | .441 |
| | 40 min | .32 | .38 | .403 |
| | 50 min | .99 | .23 | .000 |
| | 60 min | 1.06 | .23 | .000 |

In addition to the grip force, the study measured participants' subjective sleepiness while driving. Fig. 3 shows the trend of the changes in the degree of subjective sleepiness. In contrast to the grip force, which decreased over time, the subjective sleepiness increased over time. Specifically, the average at first 10min was 4.65 (SD = 1.40) , 5.29 (SD = 1.30) at 20min, 5.48 (SD = 0.85) at 30min, 5.39 (SD = 1.28) at 40min, 5.32 (SD = 1.17) at 50 min, and 5.45 (SD = 1.29) at 60 min. Repeated measures ANOVA was used to verify the changes in the degree of subjective drowsiness over time. The sphericity assumption was tested using the Mauchly's test ($p > .05$) and the Greenhouse Geisser correction was applied. After the difference reached the significant level ($F$ (3.08, 89.31) = 13.08, $p < .001$), a post hoc test was used to identified the differences for the degree of subjective drowsiness over time (Table 2). The post hoc test revealed that the degree of subjective sleepiness significantly increased after 20 min. This tendency was maintained until the end of the experiment.

Table 2. Results of Post hoc test for degree of subjective sleepiness over time

| Comparison | | mean difference | *SE* | *P* |
|---|---|---|---|---|
| 10 min vs. | 20 min | -.65 | .22 | .007 |
| | 30 min | -.84 | .21 | .000 |
| | 40 min | -.74 | .31 | .025 |
| | 50 min | -.68 | .28 | .021 |
| | 60 min | -.81 | .31 | .013 |

## 4. DISCUSSION

The purpose of the study was to identify the validity of detecting driver fatigue using the grip force on the steering wheel. The changes in the grip force were measured while the participants performed a simulation task. In addition, the subjective sleepiness was measured to increase the validity of the measurements.

The results indicated that the grip force decreased over time during the 1 hour driving and it decreased significantly after 50 min. In contrast, the degree of subjective drowsiness increased over time and increased significantly after 20 min. Therefore, as the degree of the drowsiness that the participants feel increased over time, the grip force decreased (Fig. 3). These results supported suggestions from previous studies that the grip force can be an alternative method to detect driver fatigue.

Interestingly, whereas the subjective sleepiness significantly increased after 20 min, the grip force decreased significantly after 50 min. This time gap indicates that the time when a driver reports that he/she is sleepy does not coincide with the time when physical changes start to occur in his/her body. In other words, the onset of physical changes was separated by 30 min. According to the study by Åkerstedt & Gillberg (1990), subjective and objective sleepiness have different causes [24]. Reyner & Horne (1998) also reported that sleepiness and falling asleep are strongly correlated but do not occur simultaneously [25]. This implies that after the drivers become aware of their sleepiness, they should prepare for the physical changes that can occur.

The results suggest that driver fatigue can be detected using the grip force, but the study had several limitations. Firstly, the participants could have been awakened by the measurements of the subjective sleepiness. The researcher asked the participants verbally about their sleepiness every 10 min. Although the measurement time for the subjective sleepiness was short (less than 10s), the participants might have stopped feeling sleepy during that time, and it could have taken them quite a long time to feel sleepy again. Another limitation was that other measures (e.g., physiological or behavioral measure) to objectively measure fatigue were not considered. Although studies have reported that physiological measures and the grip force are highly correlated [20], it is recommended to detect driver fatigue with multiple measures because sleepiness is a very complicated phenomenon [19]. Despite these limitations, this study identified the decrease in the grip force over time, suggesting that measuring the grip force can be a new method to detect driver fatigue. In future studies, it is necessary to measure other objective measures along with the grip force.

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