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# Microsaccades generated during car driving

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*Abstract*— **Microsaccades together with drift and tremor are fixational eye movements that are generated when we try to fixate our gaze on a visual target. Besides their function in vision to prevent neural adaptation to unchanging retinal image, microsaccades have been studied in neuroscience as an indicator of attentional states for the last decade. Most of microsaccade researches have been conducted in unnatural laboratory environments, using controlled artificial visual stimuli. Thus, little is known about the characteristics of microsaccades in natural viewing conditions. Here we attempted to evaluate microsaccades during car driving condition in the aim of estimating driver's spatial attention. We demonstrate that microsaccades are generated during car driving, and the rate of microsaccade generation is modulated by road conditions such as appearance of pedestrians or/and other cars.**

## I. Introduction

In recent years, sleepy or inattentive driving is a major cause of fatal car accidents in Japan, while overspeed was by far the worst cause 20 years ago. To prevent tragic car accidents caused by inattentive driving, it is therefore highly demanded to monitor driver's attention in a practical way. Microsaccades together with drift and tremor are fixational eye movements that are generated when we try to fixate our gaze on a visual target. In addition to their function to prevent visual fading due to neural adaptation to unchanging retinal image [1], microsaccades have been extensively studied in neuroscience for the last decade as an indicator of covert spatial attention. Most of the experiments evaluating microsaccades have been conducted in laboratories, using unnatural visual stimuli. In contrast, little is known about the characteristics of microsaccades under natural free viewing conditions [2] including those during car driving. One study has evaluated microsaccades during driving simulation, and found that microsaccades were generated and significantly increased when more visual attention shifts occurred in an artificial driving environment [3]. However, to the best of our knowledge, no study has been conducted to evaluate microsaccades during real car driving in which significantly different eye movements are generated in comparison with simulated driving conditions. For example, to look at visual objects at different distances, convergence and divergence eye movements are generated in real car driving, while a change in vergence angle is not required in driving simulation due to the fixed distance from the driver to simulator monitors or screens. Also, the vestibulo-ocular reflex (VOR) is evoked in real car driving due to unevenness of the road, while in most driving simulations including [3], head movements are not simulated. Here we attempted to measure eye movements of human subjects during car driving condition in the aim of estimating driver's attentional states by using microsaccades. We demonstrate that microsaccades are generated during real car driving, even in parallel with the VOR, and the rate of the microsaccade generation is modulated by road conditions such as appearance of pedestrians or/and other cars.

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## II. Methods

### A. Eye tracking during car driving

To measure eye movements including microsaccades that are usually defined small saccades (amplitude < 1 degree), we employed EyeSeeCam (Univ. of Munich hospital) that has minimum interference with subject's field of view while driving a car (Fig.1). Other than binocular horizontal and vertical eye positions, the eye tracker records binocular pupil sizes, and three-dimensional angular and linear head motions. These data are stored into a SSD of a MacBook pro (Apple Computer) via an IEEE1394 connection. It also stores video-images taken by the two eye cameras from which right and left eye positions are separately extracted, and those by a scene camera that cover visual scenes of the subject' head direction. These data together with time stamps were recorded synchronously at the sampling rate of approx. 220Hz. Only the results of eye movement and visual scene analyses are presented in this manuscript.

### B. Experimental Procedure

Three subjects (21, 22, and 45 years old) with normal vision participated in the experiment. A 5-passenger sedan was used in the current experiment (Fig.2). All subjects have had driver's license for more than 1 year and drive their car daily.

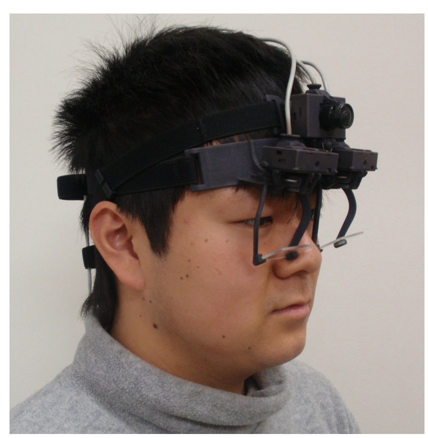

Figure 1. The eye tracker used in the experiment. Right and left eye infrared (IR) video images reflected on dichroic mirrors under each eye are taken by two IR cameras above each eye. The camera on the subject's forehead is a black and white camera to take visual scenes to which the subject is facing.

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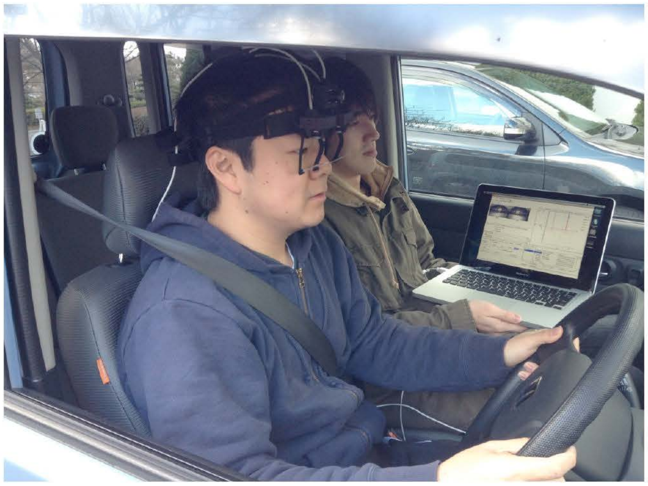

Figure 2. A subject wearing the eye tracker (EyeSeeCam) in the car used in the experiment, and an experimenter holding a PC by which the eye tracker is controlled and all the recording data are stored thru an IEEE 1394 connection.

Prior to the driving experiment, subjects performed eye position calibration of EyeSeeCam outside of the car. Then they started driving the car on the campus road in Chubu University Kasugai Campus for approx. 2 km consisting of straight and curved courses (Fig.3). All experiments were conducted in the daytime either under cloudy or fine weather condition. Pedestrians and other cars appeared in an ad hoc manner during each driving experiment. The subjects were instructed to drive as usual at adequate speeds depending upon the road conditions they encountered. Each driving experiment lasted 6 to 8 minutes (Table 1). EyeSeeCam data were recorded throughout the experiment from the starting point to the end (Fig.3).

### *C. Data Analysis*

The right and left eye position data together with the time stamps recorded by the eye tracker were exported into MATLAB (Mathworks JAPAN) for microsaccade analyses. Firstly, all data were resampled at 220Hz because the time stamp data showed they were often sampled slightly differently from the original setting. Saccades including microsaccades were detected by using velocity and acceleration thresholds that were set manually for each subject after a noise elimination process employing a 3-point moving average filter. The velocity and acceleration of eye movements were calculated as the first and second derivatives of the resampled eye position data, respectively by using a FIR filter whose coefficients are $[-f_s/2, 0, f_s/2]$, where $f_s$ is the sampling frequency 220Hz. In the present analysis, we focused more on horizontal eye movements, as they are more pronounced than the vertical eye movements in the present driving experiment. Thus saccades whose horizontal components are less than or equal to 1 degree are detected first, then the amplitudes of their vertical components are referred to, and used to calculate their amplitudes in actual saccade directions. If the amplitudes are less than or equal to 1 degree, the saccades are considered as microsaccades. The threshold (1 degree) has been employed in other related researches to define a microsaccade [4].

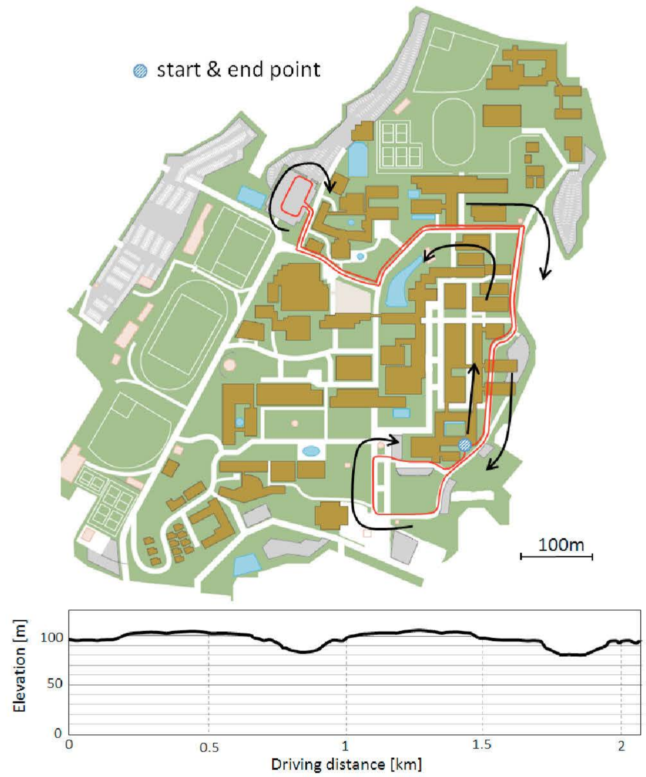


Figure 3. The route taken in the driving experiment (red line in the upper map) and elevation data along the route (lower panel). Black arrows in the upper map indicate turning direction. Note that both right and left turns, and elevation changes may induce the vestibulo-ocular reflex.

## III. Results

### *A. Are microsaccades generated during real car driving?*

Data with low noise were successfully recorded throughout the driving experiment in each subject under a wide range of changes in daylight intensities. Example traces of recorded horizontal and vertical eye positions are shown in Fig.4, and their magnified traces are in the inset to show an example microsaccade (red arrow). As exemplified in the inset of Fig.4, microsaccades were observed during car driving under a natural viewing condition in all the subjects participated in the present experiment. This is the first demonstration that shows that microsaccades are generated during real car driving.

To confirm how different the detected microsaccades from ordinary exploratory saccades, we made a histogram of amplitudes of saccades generated during the driving experiment (Fig.5 left panel), and the main sequence (Fig.5 right panel) that have been extensively referred to in order to confirm quality of recorded data and data analyses to detect microsaccades. Note that the main sequence is continuum from microsaccades to saccades and its shape including variability and linearity is comparable to those that have been demonstrated in other microsaccade researches [4].

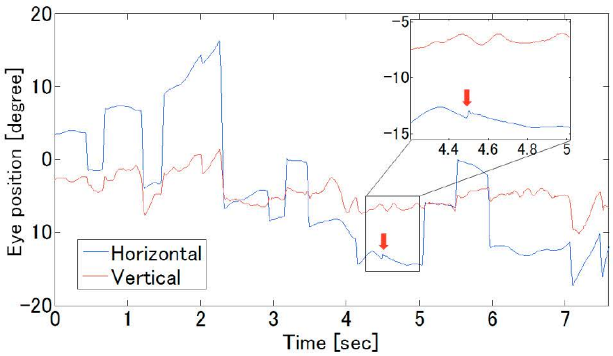


Figure 4. Example horizontal eye position data recorded during car driving. The inset is magnified eye position where microsaccades were generated.

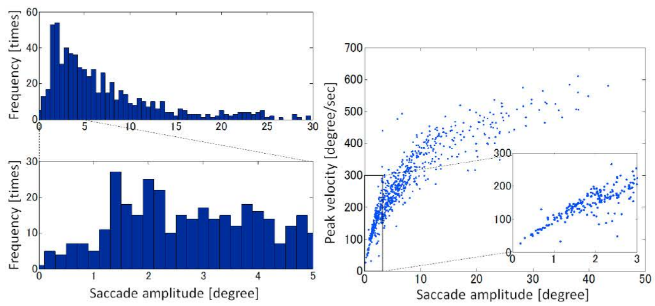


Figure 5. Histogram of amplitudes of saccades generated by sub. A during the driving experiment (left panel) and the main sequence plotted as saccade amplitude vs. saccade peak velocity (right panel).

## *B. Microsaccade during VOR*

In the present driving experiment, many microsaccades are observed on top of smooth eye movements that are in most cases evoked as the vestibulo-ocular reflex (VOR) as shown in Fig.6. During car driving, drivers' head is moved naturally by themselves, or inevitably by unevenness of the road. These head movements evoke the VOR that is a compensatory slow-phase eye movement to stabilize retinal images during head motion [5]. As the VOR is not induced or very small, if any, in ordinary microsaccade experiments conducted in laboratories, the current observation is novel in that it manifests that microsaccades can be generated in parallel with ongoing VOR. It has been confirmed in our different studies that the VOR is evoked continuously during real car driving even on a well-maintained smooth highway (unpublished observation). Thus the present observation that microsaccades can be generated on top of the VOR assures the possibility of microsaccades as an estimator of car driver's attentional states.

## *C. Microsaccade rate*

The rate of microsaccade generation is known to decrease under high cognitive load [6]. We calculated the microsaccade rates defined as the number of microsaccades per second during the driving experiment for each subject (Table 1). Two subjects (Sub.A and C) produced similar microsaccade rates while Sub.B produced a smaller rate. In either case, the values are comparable to or slightly smaller than those observed in laboratories in which subjects were asked to fixate on an artificial visual target [6][7].

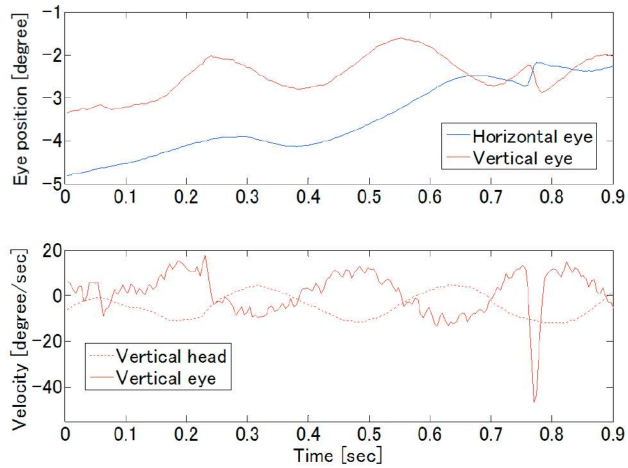


Figure 6. Example of microsaccades generated during the VOR. Upper panel: horizontal (blue) and vertical (red) eye position traces including a microsaccade at around 0.78 sec during VOR. Lower panel: Vertical head velocity (dotted red) induced by unevenness of the road and vertical eye velocity (solid red) evoked as the VOR to compensate for the head motion.

Table 1. Microsaccade rate during car driving

| Subject | Driving time [sec] | Num. of microsaccades | Microsaccade rate [/sec] |
|---|---|---|---|
| Sub.A | 400 | 61 | 0.15 |
| Sub.B | 478 | 24 | 0.05 |
| Sub.C | 432 | 80 | 0.19 |

Table 2. Microsaccade rates with and without pedestrians or/and other cars during car driving.

| Subject | Microsaccade rate with pedestrian or/and car [/sec] | Microsaccade rate without pedestrian or/and car [/sec] |
|---|---|---|
| Sub.A | 0.41 | 0.08 |
| Sub.B | 0.08 | 0.04 |
| Sub.C | 0.20 | 0.18 |

Next we divided the road conditions into two categories; 1) with pedestrians or/and other cars in the field of view of the subjects, and 2) without any pedestrians or/and cars in the field of view of the subjects. In the with-pedestrian/car condition, the subjects should have paid attention to pedestrians and/or other cars while in the without-pedestrian/car condition, they didn't have to. The microsaccade rates calculated in each condition for each subject are summarized in Table 2. In all the subjects, their microsaccade rates are greater under the with-pedestrian/car condition than those under the without-pedestrian/car condition.

# IV. Discussion and Conclusion

In the present study, we demonstrated for the first time that microsaccades are generated in human subjects during natural car driving, and their microsaccade rates are modulated by the road conditions in which pedestrians or/and other cars appear in their field of view. We showed that microsaccade rates increased when pedestrians or/and other cars are around. This result is somewhat contradictory from the result of a recent study [6] that used an artificial fixation point and showed higher attentional loads were associated with lower microsaccade rates. In contrast, another study [2] conducted under a free-viewing condition showed that microsaccade rate increased with more demanding visual search tasks. Our present result obtained under a free-viewing condition during car driving agrees with this evidence. We also found that microsaccades can be superimposed on smooth eye movements evoked as the vestibulo-ocular reflex (VOR). Although no study has demonstrated co-occurrence of the VOR and a microsaccade, the result is not surprising, because the VOR is often interrupted by resetting saccades that share neural mechanisms with exploratory saccades, and microsaccades also share the neuronal mechanisms with exploratory saccades. The VOR is inevitably induced during car driving due to head motion caused by unevenness of the road. Therefore, the present results assuring the modulation of microsaccade rate with or without pedestrians/cars, and the co-occurrence of microsaccades with the VOR lead us to conclude that microsaccade is a possible practical physiological indicator for monitoring attentional states of car drivers.

## ACKNOWLEDGMENT

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