Spontaneous vs. gaze shift-induced blinks for assessing driver drowsiness/inattention by Electrooculography

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Abstract

Driver monitoring systems with focus on drowsiness and inattention aim to reduce car-crashes. To achieve this goal, previous research has shown that driver eye blink features (blink frequency, duration etc.) are correlated to some extent with drowsiness. Hence, within a level of uncertainty they can contribute to driver drowsiness warning systems. In order to improve such systems, we investigated blink characteristics with respect to their different origins. We observed that in a real road experiment using electrooculography, blinks occur both spontaneously or due to gaze shift. Gaze shifts between fixed positions, which occurred due to secondary visuomotor task, induced and modulated the occurrence of blinks. Moreover, the direction of the gaze shift affected the occurrence of such blinks. Based on the eye movements during another experiment in a driving simulator without a secondary task, we found that the amount of gaze shift (between various positions) is positively correlated with the probability of the blink occurrence. Therefore, the paper recommends handling gaze shift-induced blinks (e.g. during visual distraction) differently from those occurring spontaneously in drowsiness warning systems.

Introduction

On highways in Germany, every fourth car crash occurs due to driver drowsiness. Moreover, drowsy truck drivers are responsible for every sixth heavy road accident involving trucks (ADAC e.v. 2012). In order to reduce the number of these crashes, assistant systems are being developed with the goal of warning drowsy or inattentive drivers on time, e.g. the *Attention Assist* system of Mercedes Benz. To improve the reliability and the efficiency of these warning systems, a reference drowsiness measure is needed. Among different physiological symptoms for assessing driver drowsiness or inattention, driver's eye movements, in particular blinks are associated with drowsiness (Hargutt 2003, Schleicher et al. 2008, Dong et al. 2011). As an example, previous studies introduced increased blink frequency as a measure related to drowsiness over time (e.g. Stern et al. 1994, Sirevaag and Stern 2000, Hargutt 2003 and Summala et al. 1999).

Are all blinks during driving drowsiness-related? Or is the occurrence of some blinks situation-dependent? Do all blinks during driving reflect the alertness of the driver to the same extent? This study aims to answer these questions, which describe the situation dependency of the blink occurrence. If the occurrence of some blinks is situation-dependent, then such blinks might (locally) affect the amount of correlation between the extracted blink's feature and driver's state in warning systems. Therefore, they should be taken out of consideration or handled differently for assessing drowsiness. Phases of visual or cognitive distractions like during data entering into the navigation system or during a mobile conversation are examples of situation dependency of the blink occurrence. In this context, Liang and Lee (2010) reported increased blink frequency in a driving simulator during cognitive and combined (cognitive and visual) distraction.

In order to investigate the aforementioned questions, an experiment is conducted to monitor the blinking behavior of 26 subjects by electrooculography (EOG) in the real road driving. The subjects performed the primary driving task and visuomotor or auditory secondary tasks. The subjects were instructed to experience fixed position gaze shift due to visuomotor task, which represents visual distraction.

On the other hand, during driving, blinks mainly occur spontaneously or due to gaze shifts (during a look in the rear-view-mirror). Moreover, we know that the driver should scan the scene and the road ahead frequently to perform the driving task properly. This brings a question: which gaze shifts (with respect to their amplitude) are more probably accompanied by a blink during driving (without performing a secondary task)? This question will be investigated by following another experiment, in which eye movements of 12 drivers in a driving simulator were collected by EOG. In this experiment we specifically studied the correlation of the amount of gaze shift to the blink occurrence.

Evinger et al. (1994) stated based on Beideman and Stern (1977):

> Gaze-evoked blinks rarely occur when making a saccade to a rear view mirror before shifting lanes, but often accompany the saccade back to straight-ahead position.

Inspired by this fact, it is also studied whether the occurrence of gaze shift-induced blinks is direction-dependent.

In this paper, first types of eye movements are introduced. Afterwards we describe the conducted experiments. Then the results of study are subsequently discussed. The conclusions are made in the last section.

Types of Eye Movements

Smooth pursuit, *saccade*, *fixation* and *blink* are typical types of human eye movements (ISO/DIS 15007-1 2013). Slow eye movements while tracking a moving object are called smooth pursuit (Leigh and Zee 1998). Saccades as fast movements of both eyes occur due to the change of the looking direction (gaze shift) to reposition the fovea from one image to another one (Enderle 2010). Based on the definition of the saccade, it occurs either only in one direction (only horizontal or only vertical) or diagonal. The time interval between two saccades is called fixation. Finally, blinks are regular and rapid opening and closing of the human eyes which contain three stages: opening, closed and closing (Hammoud 2008).

Methods

Experiment 1: Real Road Drive

The detailed experiment design is described by Sonnleitner et al. (2013). The experiment was originally designed for studying the neurophysiological correlates of attentional shift during real road driving while performing secondary tasks. Here, the parts relevant to our issues are explained.

A total of 26 subjects participated in the experiment conducted with an S-Class and an E-Class Mercedes. The eye movement of the subjects was measured by EOG at 250 Hz with 6 electrodes: four electrodes for horizontal (EOG_H) and vertical (EOG_V) movements and two as reference and ground (ActiCap, Brain Products GmbH). EOG_H and EOG_V are defined as follows

$$EOG\_V = electrode_{up} - electrode_{down} \quad (1)$$

$$EOG\_H = electrode_{right} - electrode_{left}. \quad (2)$$

During the experiment subjects should perform the primary driving task followed by four blocks of secondary tasks within 40 minutes on the highway. The secondary tasks contain both visuomotor (representative of navigation system's demand) and auditory (comparable with mobile conversation) tasks. All subjects were instructed to always prioritize the primary task and to drive under official traffic regulations. The maximum speed allowed was 130 km/h. During the tasks, no overtaking maneuver was allowed. Each block contained three minutes of visuomotor task, 1.5 minute of driving with no secondary task, three minutes of auditory task and finally 1.5 minute of driving with no secondary task as shown in Figure 1. For all subjects the blocks are presented at the same time.

The start and end of each block has been saved automatically. This means that the time gaps before and after the beginning and end of blocks have been discarded.

This study sampled EOG signals down to 50 Hz and achieved the same results as for 250 Hz signals.

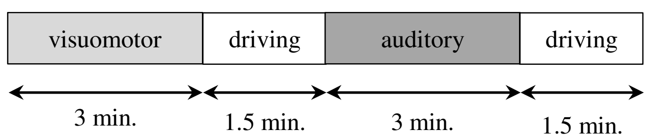


Figure 1 One block of experiment of the real road driving situation

It should be mentioned that by applying the power analysis a total sample size of 26 was needed (Sonnleitner et. al 2013).

Visuomotor secondary task

For the visuomotor task, a 2x2 matrix of four Landolt rings was shown on a display located at the central console on the right side of the navigation system. The subject had to determine which side of the screen (right or left) contains rings with different directions of openings (see Figure 2) by pushing on an external number keypad (4: left, 6: right) located within driver's reach on the lower central console. In this study, the number of correctly identified rings is not evaluated as just the gaze shifts between the road and the screen are of interest.

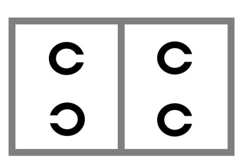


Figure 2 An example of the visuomotor secondary task

Auditory secondary task

During this task, the subjects listened to an audio book, in order to detect the German definite article "die" by pressing a button fitted to their left index finger. At the end of each block, subjects answered a question about the content of the presented audio book. Again, the answers are not evaluated here.

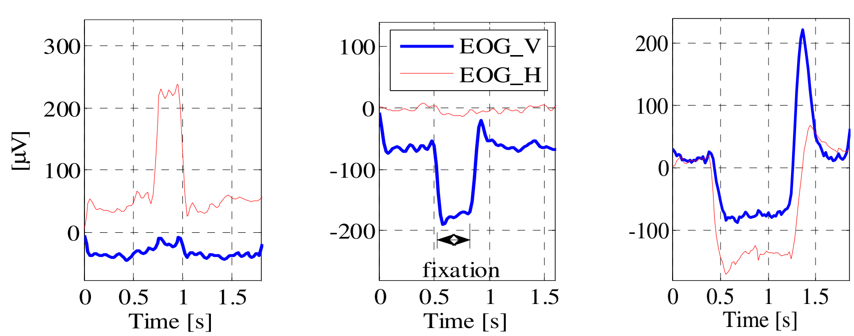
Experiment 2: Driving Simulator

During the second experiment, 12 subjects (not the same subjects as in the previous experiment) were asked to drive in a driving simulator as long as they could, in order to collect a data set with the most relevant eye movements to drowsiness which was assessed by Karolinska Sleepiness Scale (Akerstedt and Gillberg 1990). The experiment was conducted at the Mercedes Benz driving simulator (Zeeb 2010) in an S-Class cabin under highly monotonous (low traffic highway) driving conditions during the night. The maximum allowed speed was 130 Km/h. On average, each subject drove 327±76 Km during 156±36 minutes. The subjects were allowed to stop driving at any time due to drowsiness. The correlation of blink features with drowsiness is not discussed in this study.

As this driving simulator has a moving-base system and the drivers experience the driving scene on a 360° projection screen, the collected data is to a large extent comparable with that of the real road driving as described by Zeeb (2010). The eye movement of the subjects was collected with the same measuring system as in the other experiment. Moreover, a camera recorded the subject's face during driving.

Data Analysis: Eye Movement Detection

Some examples of the collected data are shown in Figures 3 and 4. Figure 3 represents saccades occurring in different directions. For a saccade occurring only in one direction, just one component of EOG varies remarkably as shown in Figures 3(a) and 3(b). However, according to Figure 3(c), for diagonal saccades, both EOG_H and EOG_V signals are informative. During driving, saccades similar to Figure 3(b) occur while looking at the speedometer. Diagonal saccades also refer to the glance at the mirrors. An example of a blink, which is only in EOG_V signal evident, is shown in Figure 4.



a) Horizontal   b) Vertical   c) Diagonal

Figure 3   Horizontal, vertical and diagonal saccades measured by EOG

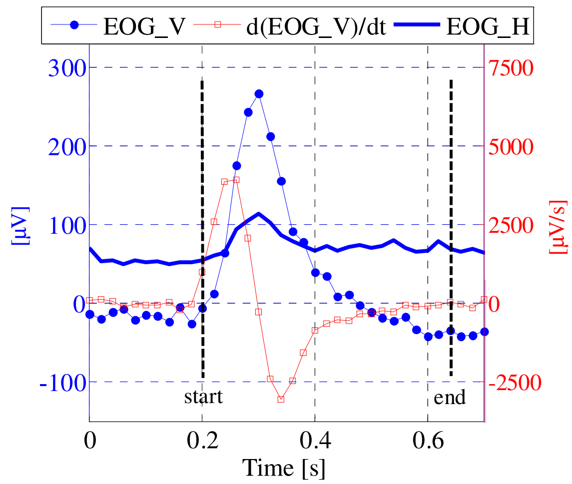


Figure 4 An example of an eye blink measured by EOG

In order to analyze the relationship between gaze shift and the blink occurrence, it is necessary to detect saccades and blinks correctly out of the EOG signals. The applied algorithm for detecting blinks and saccades is based on comparing the derivative signal of the EOG signals with separate thresholds (Ebrahim et al. 2013, not discussed in details here). Part of the detection algorithm is similar to the approach used by Hu and Zheng (2009) and Wei and Lu (2012).

The derivate of the EOG_V signal is shown in Figure 4 calculated by applying the Savitzky-Golay filter (polynomial order = 1, frame size = 7) (Savitzky and Golay 1964). Start and end points of a blink are considered with respect to the sign changes of the derivative signal (first sample after a sign change, see Figure 4). The second saccade of Figure 3(c) is also time-locked to a blink (i.e. blink and saccade happen simultaneously).

Results

The results presented in this section are based on the detected blinks and saccades out of the EOG signals.

Experiment 1: Secondary Task during Real Road Drive

Time-on-task: Does the saccade rate change over time (four blocks) during the visuomotor secondary task?

For investigation of the variable time-on-task, first the number of all detected saccades out of the EOG_H signal during the visuomotor secondary task is calculated. As mentioned before, this task was repeated four times by each subject and each time for three minutes. The number of saccades per minute (saccade rate) is calculated during each block for each subject. Figure 5 shows the mean and the standard deviation of the calculated values for each block separately. By applying the analysis of variance (one-way repeated measures ANOVA), it is examined whether the saccade rate has changed significantly over time. It should be mentioned that all assumptions of ANOVA are fulfilled (i.e. independency and normality of observations and the homogeneity of their variances). The corresponding H_0 hypothesis states that the means of different groups of measurements (blocks) are equal. Since the calculated p-value is 0.30 at confidence level of 95% ($\alpha = 0.05$) with $F_{3,75} = 1.28$, the H_0 hypothesis cannot be rejected ($0.3 > \alpha$).

Consequently, the numbers of gaze shifts during the visuomotor task are independent of the variable time-on-task considering all subjects and all blocks.

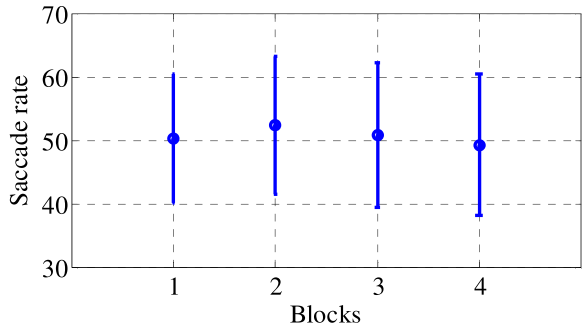


Figure 5 **Saccade rate for variable time-on-task (four blocks). Error bars represent the standard errors of the means.**

Time-on-task: Does the blink rate change over time (four blocks) during the primary and secondary tasks?

Similar to the previous step, number of blinks per minute (blink rate) is investigated during each block and each task separately. The calculated values by applying ANOVA for repeated measures are $F_{3,57}$ = 1.05 with p-value = 0.37 for visuomotor task, $F_{3,75}$ = 0.27 with p-value = 0.85 for driving task and $F_{3,57}$ = 1.08 with p-value = 0.36 for auditory task. According to the p-values which are all larger than $\alpha = 0.05$, it can be concluded that there is no significant difference between the means of blinks rates during four blocks. Therefore, the blink rate is also independent of variable time-on-task.

How many saccades are time-locked to blinks during the visuomotor task?

Here it is shown what percent of saccades are time-locked (i.e. occurring simultaneously) to blinks during the visuomotor task. In order to find that, all saccades during the visuomotor task are detected in the EOG_H signal. Then, according to the detected blinks in the EOG_V signal, the number of saccades accompanied by blinks (in percent) is calculated as shown in Figure 6.

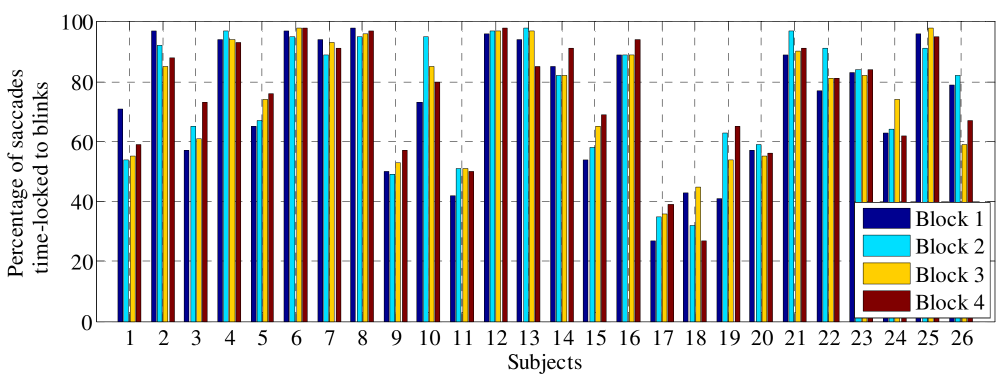


Figure 6 **Percentage of saccades time-locked to blinks for all subjects and all blocks during the visuomotor task**

As Figure 6 shows, on average over all blocks, for 14 subjects (2, 4, 6, 7, 8, 10, 12, 13, 14, 16, 21, 22, 23, and 25) over 80% of all saccades due to the visuomotor task are time-locked to blinks. For 9 subjects (1, 3, 5, 9, 15, 19, 20, 24 and 26) gaze shift-induced blinks accompany from 50% to 75% of saccades. Interestingly, the calculated percentage is less than 50% for only 3 subjects (11, 17 and 18). All in all, for most of the subjects gaze shift induces the blink occurrence.

Does the occurrence of blinks time-locked to saccades depend on the direction of saccades?

As mentioned in the introduction, inspired by Evinger et al. (1994), Figure 7 shows whether the occurrence of gaze shift-induced blinks is dependent on the direction of the saccade. The saccades are either toward the road or towards the screen (between fixed positions). The bars of this figure represent the number of saccades time-locked to blinks (in percent) with respect to their direction. With the exception of Subject 19, for all subjects the number of saccades time-locked to blinks is larger while looking towards the road (M = 88%±16.7). However, for the other direction, namely towards the screen, there exist different behaviors (M = 61%±31.1).

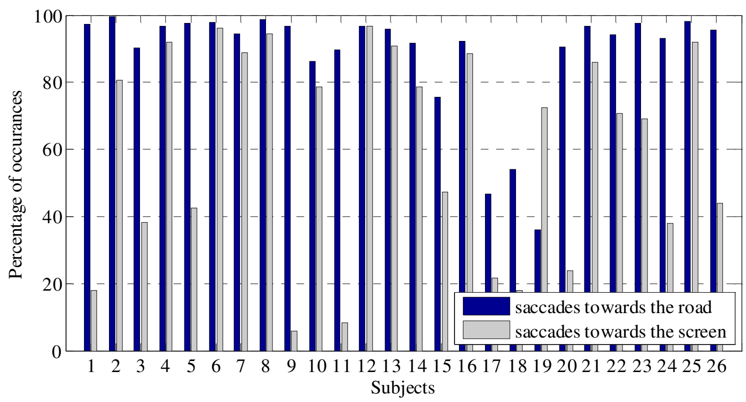


Figure 7 Percentage of blinks time-locked to saccades with respect to saccade direction averaged over all blocks during the visuomotor task

In order to categorize the behaviors, the values of bars of Figure 7 are plotted versus each other in Figure 8 (dark bars as the x-axis, light bars as the y-axis). The red line in this plot refers to the $y = x$ line and is plotted for better understanding. The ellipses show distinguishable clusters A and B.

Cluster A contains 14 subjects, for whom, at least 65% of saccades induce the occurrence of blinks in both directions. On average, 95%±3.50 of saccades towards the road and 85%±9.00 of saccades towards the screen are accompanied by blinks. Consequently, for this cluster, the occurrence of gaze shift-induced blinks is less direction dependent. On the other hand, for the subjects of cluster B, the direction of saccades seems to affect the occurrence of blinks to a greater extent. For this cluster, on average, 93%±3.39 of saccades towards the road are accompanied by a blink, while only 27%±15.38 of saccades towards the screen induce the occurrence of blinks. Therefore, in one direction (towards the road), the blink occurrence is more dominant. For subjects 15, 17 and 18, although the saccades towards the road have induced more blinks than those towards the screen, the overall number of induced blinks is less in comparison to that of the mentioned clusters.

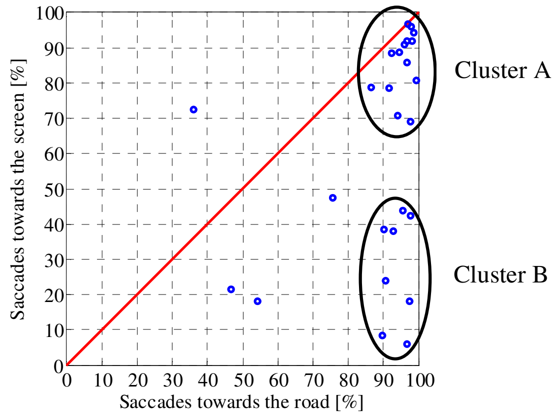


Figure 8 **Scatter plot: number of saccades accompanied by blinks with respect to their direction during the visuomotor task. Ellipses show two clusters.**

Does performing secondary tasks affect the blink rate in comparison to the primary task?

Here it will be studied whether performing secondary tasks affects the blink rate in comparison to the driving task. In order to analyze this, all detected blinks during each of these tasks are considered for all subjects, independent of the fact of whether they are gaze shift-induced or not. Figures 9(a) and 9(d) show the scatter plots of blink rates for driving versus visuomotor and auditory tasks with the correlation values of $r = 0.32$ (p-value = 0.008) and $r = 0.79$ (p-value < 0.001), respectively. According to the r values and the scatter plots, it can be concluded that performing a visuomotor task affects the blinking behavior to a larger extent in comparison to the auditory task (0.32 < 0.79).

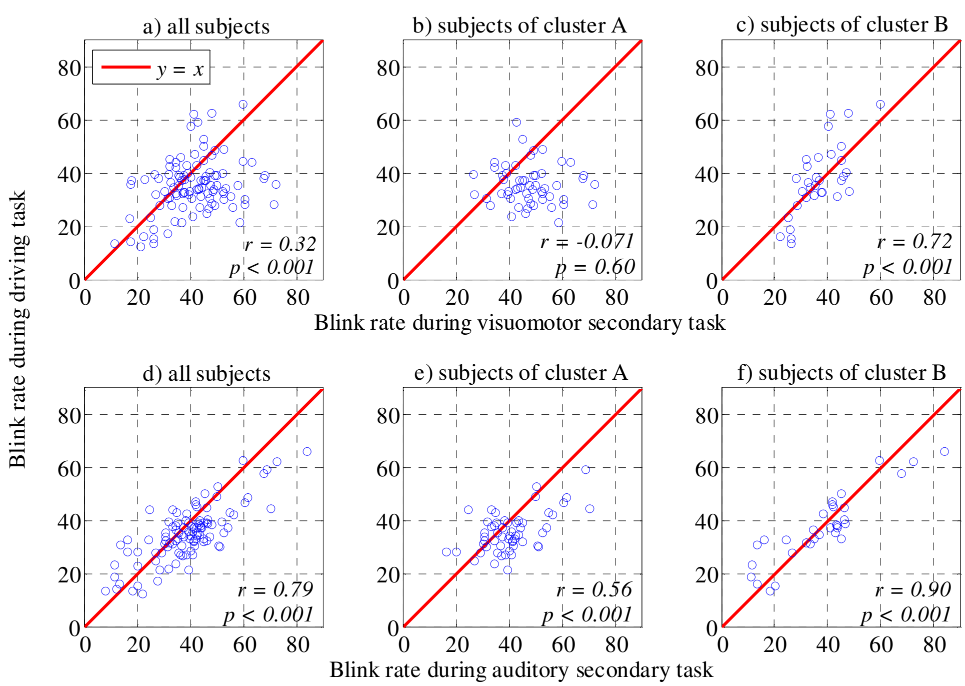


Figure 9 **Scatter plots of blink rate: visuomotor vs. driving task (top row), auditory vs. driving task (bottom row)**

Similar scatter plots for the subjects of clusters A and B are also shown in Figure 9, comparing the blink rates during both visuomotor (9(b), 9(c)) and auditory task (9(e), 9(f)) versus driving task. According to the correlation values, it seems that for cluster B with direction-dependent gaze shift-induced blinks, blink rate is less affected during the visuomotor task in comparison to cluster A as the *r* values are larger than those of the cluster A.

Table 1 shows the results of applying ANOVA for repeated measures to investigate the significant differences of the blink rate between tasks. Overall, the mean of blink rate for visuomotor task is significantly different from that of the driving task ($0.012 < \alpha = 0.05$). This is also the case for the auditory versus driving task ($0.011 < \alpha$). According to the values related to cluster B with direction-dependent gaze shift-induced blinks, the blink rate does not change significantly during the secondary tasks ($0.831 > \alpha$, $0.800 > \alpha$). However, for cluster A it is the opposite.

Table 1 Values of ANOVA to assess the significant difference between means of blink rates for all tasks

	Visuomotor vs. driving	Auditory vs. driving
All subjects, all blocks	$F_{1,25} = 7.26$, $p = 0.012$	$F_{1,25} = 7.43$, $p = 0.011$
Subjects of cluster A	$F_{1,13} = 14.35$, $p = 0.002$	$F_{1,13} = 5.66$, $p = 0.033$
Subjects of Cluster B	$F_{1,7} = 0.05$, $p = 0.831$	$F_{1,7} = 0.07$, $p = 0.800$

How is the blinking behavior affected during performing the visuomotor task?

Figure 10 shows what percentage of blinks during the visuomotor task is gaze shift-induced (on average over all blocks). In other words, after detecting all blinks in EOG_V signal, just those blinks time-locked to saccades of the EOG_H signal are considered. On average, 91%±8.66 of blinks occur simultaneously with a gaze shift. Consequently, during the visuomotor task the occurrence of spontaneous blinks is highly modulated by the gaze shift frequency. That means, the subject either does not blink or blinks simultaneously during the gaze shift. This fact is shown in scatter plot of Figure 11(a), where the blink rate is plotted versus the saccade rate during the visuomotor task. Figures 11(b) and 11(c) show the same values for clusters A and B, respectively.

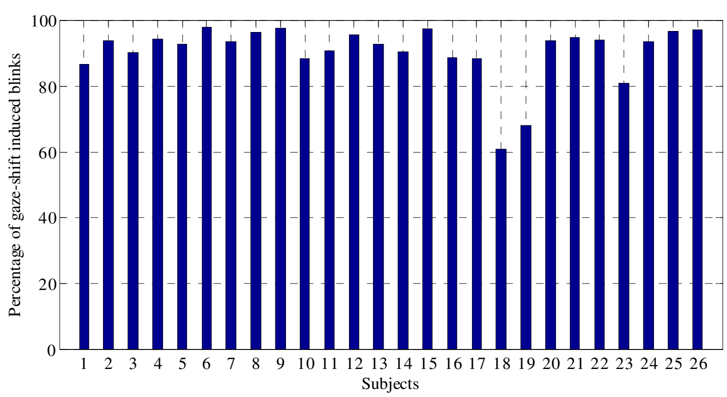


Figure 10 Percentage of blinks time-locked to saccades for all subjects averaged over all blocks during the visuomotor task

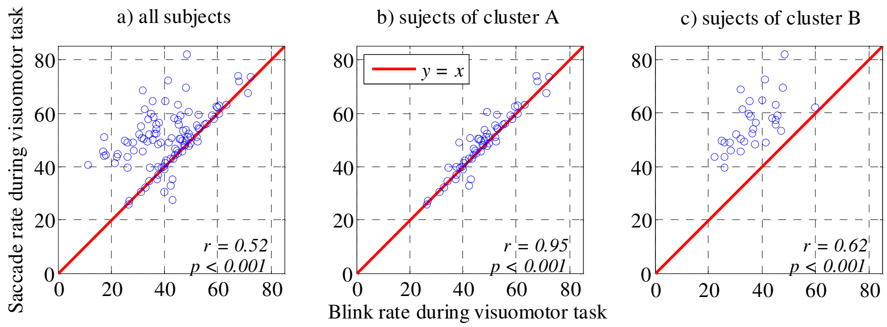


Figure 11 Scatter plot: blink rate vs. saccade rate during the visuomotor task

Figures 12 and 13 show two representative examples of the EOG signals during the visuomotor and driving task. In Figure 12(a) (Subject 8), during the visuomotor task, not only the blink frequency is completely modulated by the saccade frequency, but also the visual task leads to the increase in the number of blinks in comparison to the driving task (Figure 12(b)). This subject belongs to the cluster A with direction-independent gaze shift-induced blinks. On the contrary, for Subject 1 from cluster B with direction-dependent gaze shift-induced blinks, number of blinks during the visuomotor task was decreased in comparison to that of the driving task (Figures 13(a) and 13(b)). It is clear that during the visuomotor task, blink frequency depends thoroughly on the saccade frequency.

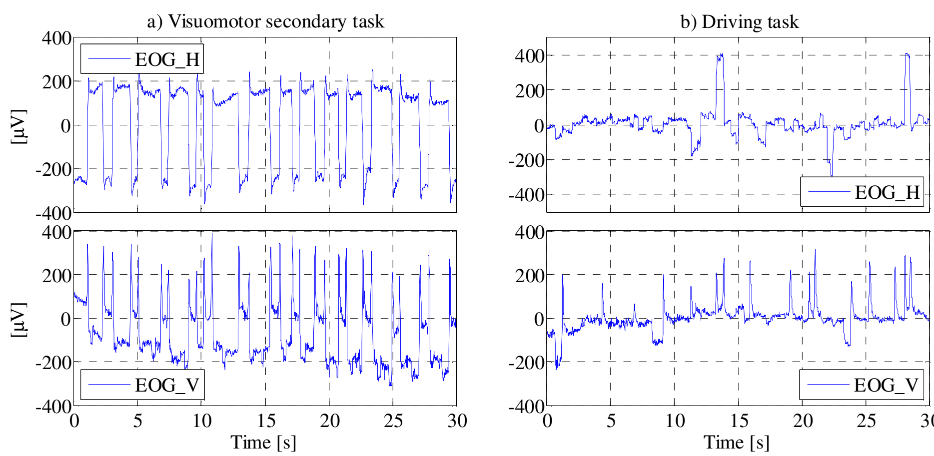


Figure 12 EOG signals during the visuomotor (left column) and driving (right column) task for Subject 8

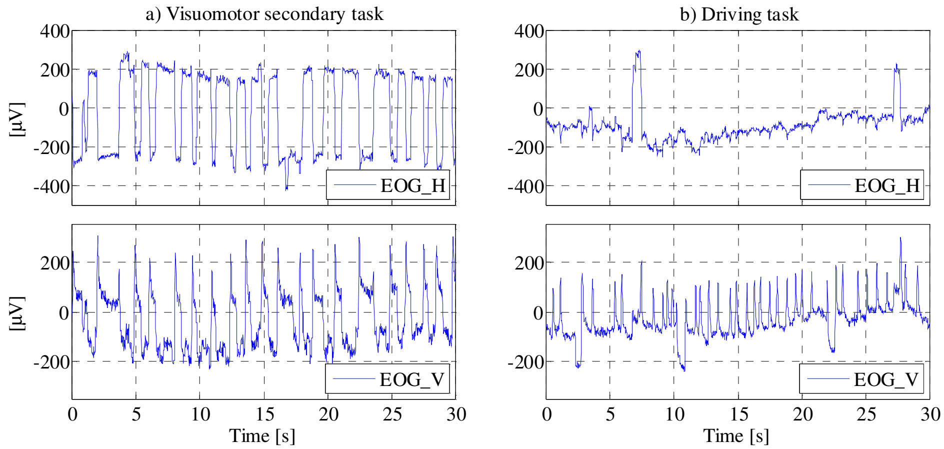


Figure 13 EOG signals during the visuomotor (left column) and driving (right column) task for Subject 1

Experiment 2: Driving Simulator

Is the occurrence of gaze shift-induced blinks correlated with the amount of the gaze shift?

During the second experiment, the subjects experienced gaze shifts between various positions without any instruction. In order to show whether the occurrence of gaze shift-induced blinks is independent of the fact that the subjects are instructed to have gaze shift (as in the first Experiment) and whether this is positively/negatively correlated with the amount of gaze shift, all horizontal saccades during the drive were studied.

A single saccade (e.g. gaze shift with some degrees to the right) measured by EOG occurs with different amplitudes from person to person (depending on the skin type, its cleanliness, etc.). Therefore, it is possible for similar saccadic eye movements not to be detected for all subjects, because detected saccades with similar amplitudes do not necessarily refer to the equal amount of gaze shift. To overcome this, only horizontal saccades are considered whose amplitudes are equal or larger than that of a look at the speedometer. In fact, all glances at the speedometer out of the EOG_V signal are extracted (controlled by video) as the minimum detectable gaze shift for each subject. Then one standard deviation of the mean of them is used as the threshold for detecting gaze shifts of the EOG_H signal. Thus, the threshold for the horizontal saccade detection is chosen individually based on the vertical saccades of EOG_V (the glance at the speedometer). Figure 14 summarizes the explained algorithm.

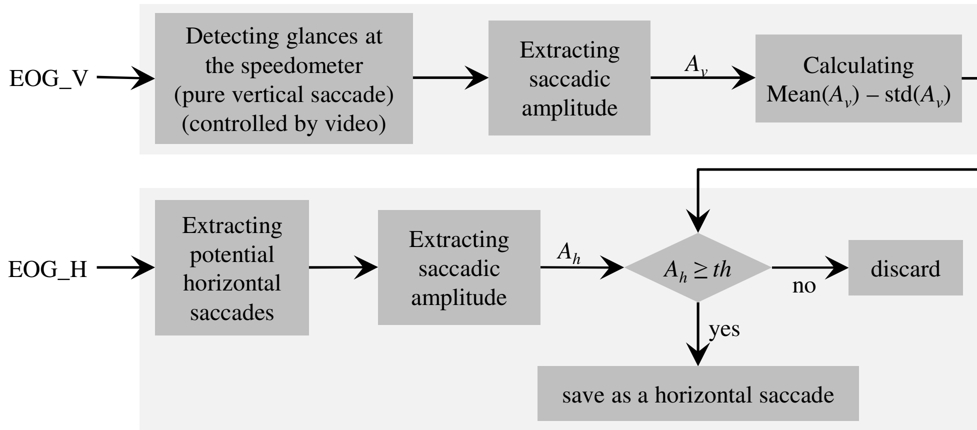


Figure 14 Algorithm for determining the threshold of horizontal saccade detection

Figure 15 shows the histogram of the absolute amplitude of all saccades fulfilling the criterion shown in Figure 14 for one of the subjects. It can be seen that small amplitude saccades (e.g. amplitudes < 200 µV) occur more often in comparison to the larger amplitude ones which refer to the gaze shift during the glance at the side/rare mirror (e.g. amplitudes > 300 µV). For balancing the number of occurrences between small and large amplitude saccades, the *k*-means clustering algorithm is first applied to divide the saccadic amplitude into two categories: small vs. large amplitude clusters. The threshold dividing the clusters is shown in Figure 15 in solid line. For most of the subjects, the number of saccades belonging to the small amplitude cluster (N_1) is larger than that of the other cluster (N_2). Therefore, out of N_1 number of saccades of small amplitude cluster, N_2 of them are selected randomly. This helps to balance the number of events in both clusters. For subjects with $N_1 < N_2$, the selection procedure is performed the other way around (see Figure 16). Afterwards, the occurrence of gaze shift-induced blinks with respect to the saccadic amplitude is studied. The selection of N_2 out of N_1 events (or vice versa) is repeated at least 100 times for each subject separately to ensure the independency of the result on the chosen saccades out of the small/large amplitude cluster. Dark histograms of Figure 17 show the amplitude of the horizontal saccades of both clusters for the 100th iteration. The solid line also indicates the border between the clusters. After balancing the number of events in each cluster, it has been calculated how many of the saccades were accompanied by blinks. The histograms of the amplitude of these saccades are shown in light color in Figure 17.

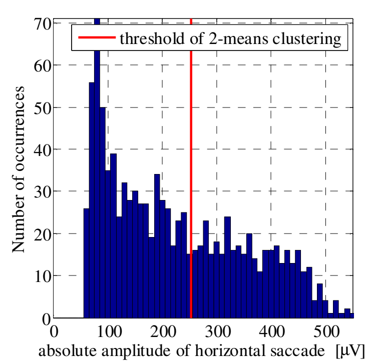


Figure 15 Histogram: absolute amplitude of saccades out of EOG_H signal

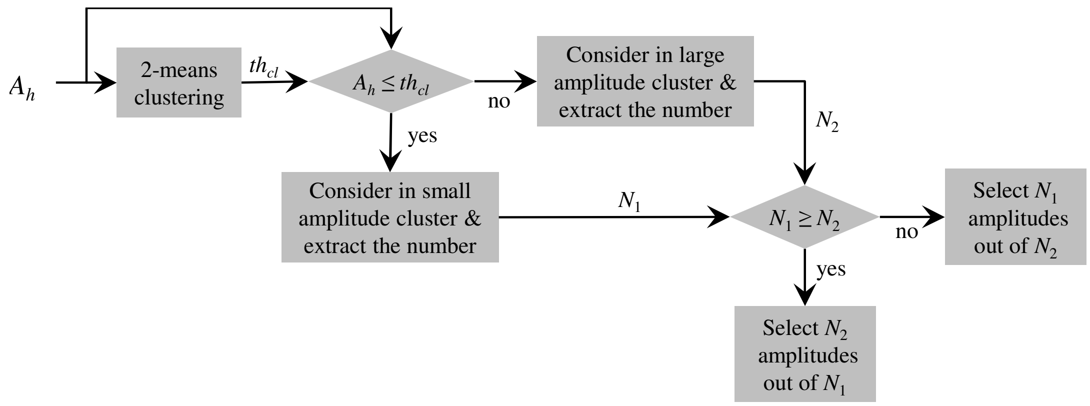


Figure 16 **The algorithm for balancing the number of small and large amplitude saccades**

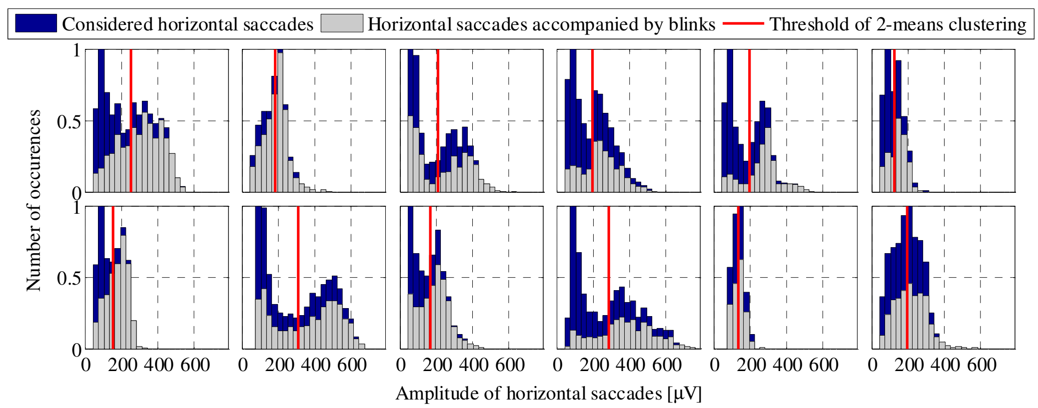


Figure 17 **Histogram: amplitude of all horizontal saccades (dark bars) and those accompanied by blinks (light bars) for all Subjects**

The scatter plot of Figure 18 quantifies the result of the histograms of Figure 17. The numbers of small amplitude saccades accompanied by blinks (x-axis) are plotted versus the same values for large amplitude saccades (y-axis) in percent averaged over 100 repetitions of selecting N_1 out of N_2 (or vice versa). For all subjects, the values are on the left side of the $y = x$ line. This implies that independent of the fact of whether the subjects are instructed to carry out a secondary task in addition to the driving task, they automatically blink more often during large amplitude saccades in comparison to small amplitude ones.

To quantify whether the categorical data: “saccade amplitude: small/large” and “occurrence of gaze shift-induced blink: yes/no” are independent or not, the contingency table (cross tabulation) is studied. Table 2 shows the result for Subject 1. By applying the χ^2 test, it can be shown whether the difference between the proportions is statistically significant. Therefore, H_0 hypothesis is formulated as “there is no relationship between two mentioned categories”. By considering the confidence level of 95% (α = 0.05), for all subjects (except for Subject 11), the p-values were always smaller than 0.001 which leads to the rejection of H_0 hypothesis. Therefore, the amplitude of the gaze shift is responsible for inducing a blink, so that the larger the amount of the gaze shift, the more probable the blink occurrence. For Subject 11, however, *p*-value was always > 0.05.

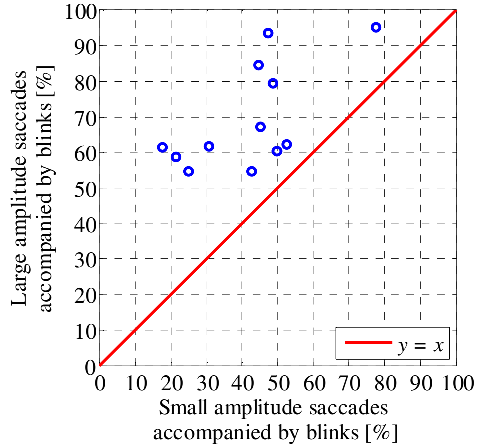


Figure 18 Scatter plot: number of saccades time-locked to the blinks with respect to their amplitude

Table 2 Contingency table: saccade amplitude vs. occurrence of gaze shift-induced blinks, for Subject 1, first selection procedure

		Amplitude of saccades		
	events	small	large	totals
Occurrence of gaze shift-induced blink	yes	151	321	472
	no	228	58	286
	totals	379	379	

Discussion and Conclusion

This study discussed the occurrence of gaze shift-induced versus spontaneous blinks in the real road and simulated driving. It was shown that during a visuomotor secondary task performed in a real road scenario comparable with the navigation system's demand, gaze shifts induce the occurrence of blinks. By repeating the tasks four times, both blink and saccade rates remained unrelated to the variable time-on-task. For 14 subjects out 26, the occurrence of such blinks is independent of the gaze shift direction. Quite the contrary, for 8 subjects, it was more probable to blink during the gaze shift towards the road. All in all, it seems that gaze shifts towards the road generally induce the occurrence of blinks to a larger extent. A possible reason might be that, during the off-road gaze shift, the driver aims to gather visual information. Thus, the eyes will be kept open, in order not to miss any information (i.e. no blinking). However, during the gaze shift towards the road, the information has already been gathered and no information will be lost during the eye closure (i.e. blinking). Consequently, the driver blinks during the on-road gaze shift.

Comparing the blink rate during the secondary tasks and the driving task, it was shown that their differences are statistically significant showing that performing a secondary task (either visuomotor or auditory) affects the blink rate. The visuomotor task impacts the blink rate more severely than the auditory task, so that it leads to the greater increase of the blink rate for most of the subjects. Moreover, it is shown that the frequency of the visual distraction completely modulates the frequency of blinking. This can be associated with the *saccadic suppression* (Goldstein 2010) phenomenon. During saccadic eye movements, the image will be blurred on the retina, so that the sensitivity to visual events reduces (Deubel et al. 2004). Therefore, the eyes will also be closed during this phase, since no visual information exists to be gathered.

On the other hand, results of the experiment in a driving simulator led to a positive correlation between the amount of gaze shift and the occurrence of blinking without performing a secondary task. This means that the larger the amount of the gaze shift, the higher the probability of blinking. Consequently, this study suggests those who consider blink rate as an indicator of drowsiness to handle gaze shift-induced blinks differently to spontaneous ones, particularly if the driver is visually or cognitively distracted. In fact, such blinks are situation-dependent and locally change the blinking behavior e.g. blink frequency.

In this study, the primary and the secondary tasks of the first experiment were performed successively. Moreover, the second experiment was deliberately designed to be monotonous for collecting the drowsiness related data (without a secondary task). In future, it is worth designing an experiment by combining both scenarios to study the effects of performing secondary tasks on the blinking behavior over longer time and during different phases of the drive.

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