Driving without awareness: Examination of the phenomenon

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Fig. 1: First occurrence of DWA and micro sleep for the test subjects during the day-drive (left) and night-drive (right).

Fig. 2: Number of DWA and micro sleep events over different stages of self-rated alertness from 10 (fully awake) to 1 (absolutely tired). No DWA or micro sleep occurred for subjective alertness > 5.

Fig. 3: Average blink duration and lid cleft during wakefulness, preceding DWA or micro sleep. While the difference between awake and DWA is statistically significant (see text) in both cases, the difference between DWA and micro sleep is not.

Table 1: Results of the one-way ANOVA for dependent measures and post hoc comparison between awake/DWA/micro sleep

Up to six keywords (selected from the keyword list).
Driving without awareness, micro sleep, driving simulator, blink behaviour, drowsiness, fatigue
Abstract
In studies concerning driver state, particularly attention loss and driver drowsiness, a phenomenon can be observed which we refer to as driving without awareness (DWA). The purpose of the study presented here is to learn more about the underlying characteristics of this symptom of driver drowsiness that occurs if the will to keep one’s eyes open overrides the physiological need of a drowsy person to close his or her eyes. The crucial part of the presented analysis is the examination of the connection of DWA and micro sleep, the risk factors for DWA and a comparison of blink parameters.

Experimental series in a driving simulator have revealed that almost every fifth driver shows states of deep unawareness during a monotonous drive on a simulated highway. The states of DWA occur predominantly together with events of so-called micro sleep.

To confirm this finding, a follow-up study with 38 test-drivers has been analyzed in which subjects appeared twice to the test, under different test conditions concerning daytime. Subsequently, the method of video analysis was applied to document acute states of DWA and of micro sleep events. Results show that DWA often precedes or accompanies micro sleep. The occurrence of DWA seems to come along with certain patterns in blink behaviour, which are more similar to micro sleep events than to a state of being awake. These findings support our assumption that DWA is a precursor of falling asleep.

1. Introduction
Almost everyone has experienced or at least heard from others about incidents on the road in which driver distraction and inattention posed a serious hazard. If for example the driver engages in a secondary task like listening to his hand-held device, eating or talking to a passenger, he might be too distracted to handle the driving task adequately. There are other inattention incidents which are directly related to the driving task like checking the speedometer or observing subsequent traffic prior to or during a lane change, which might cause an accident, too. Some other type of inattention can be described as non-specific eye glances away from the relevant traffic. Finally, a very important driver inattention issue is driver drowsiness.

As has been shown recently in a report of the National Highway Traffic Safety Administration (2006), all these issues of driver inattention are a high safety risk on highways. There has been a long-time consciousness about the negative effects of driver distraction on driving performance. Research topics like driver distraction and driver fatigue are still up-to-the-minute among transport researchers, while one topic still remains hardly investigated: driving without awareness (DWA). In this trance-like state the driver’s capacity to avoid a collision can cease to exist, even with his eyes being wide open. Other terms used synonymously to driving without awareness or referring to similar occurrences are highway hypnosis, driving without attention mode or time gap experience. We want to address this phenomenon in this study. To introduce DWA we will first give a short historical overview on this topic.

1.1. General overview
The phenomenon “driving without awareness” is known for many years, a very early publication to this topic was released 77 years ago by Miles (1929). He observed that in very important tasks of high responsibility like driving, the will to keep the eyes open and to not fall asleep can end in
a state of sleeping with the eyes open.

Williams and Shor (1970) state that in an even earlier article from the year 1921 the phenomenon of “road hypnotism” was first mentioned. The phenomenon was accounted as some kind of hypnotic state, implying staring into space or at a fixation point on the horizon, unable to react adequately to hazardous situations. For this reason, some authors labelled it “highway hypnosis” (Williams, 1963). Monotonous roads and bright points of fixation were considered as inducing factors. Also other authors like Shor and Thackray (1970) report circumstances that promote highway hypnosis, like repetition and monotony, minor physical fatigue, and the ease of learning the task, until it becomes “automatic”.

Theories about highway hypnosis have done little to explain its origin and nature. Their merit was to offer a very accurate overall descriptive analysis of highway hypnosis as a trance-like state, with the expressionless or glassy stare as one of its typical physical characteristics (e.g. Williams, 1963).

Substantial progress in the research domain was made by Wertheim (1978), who tried to validate a theory about eye movements and their impact on highway hypnosis in systematic studies under experimental conditions. Wertheim was not only one of the very few researchers who tried to conduct empirical testing, but also one of the very few who tried to provide an explaining theory. From his point of view highway hypnosis is the effect of a shift from processing outward visual stimuli to internal motor programs. The shift is triggered by repetitive eye movements in a visual surrounding of high predictability.

More than ten years later there was another significant move forward in the theoretical discussion of the phenomenon. On the conference Vision in Vehicles III several researchers presented different proposals explaining and interpreting highway hypnosis. Wertheim presented a theoretical analysis, in which he called the term “highway hypnosis” into question: The description of this phenomenon as a hypnotic trance had not helped to explain the factors generating and inducing this state. Kerr (1991) proposed the term “driving without attention mode” for the phenomenon. Consistent with Wertheim’s suggestion he sees the main characteristic of this state as the loss of awareness due to automated processing of perception induced by a highly predictable visual scene. At the same conference, Brown (1991) claims that experimental validation should help to differentiate between the influences of sleep, trance and attention on the phenomenon. Brown himself (1994) does not try to explain or validate theories about the phenomenon he himself calls “driving without awareness”.

One point that distinguishes early specifications of highway hypnosis as a tendency to become drowsy and fall asleep when driving an automobile (Williams and Shor, 1979) from some of the newer ones is the relation of DWA to fatigue. A hypnagogic state, as directed to in the term “highway hypnosis”, can be described as a drowsy interval between waking and sleeping (e.g. Schachter, 1976). The assumed relation between DWA and fatigue differs from author to author. While Williams (1963) sees fatigue as a condition that promotes but is not necessary for inducing this trance-like state, Shor and Thackray (1970) see the phenomenon as closely related to severe drowsiness and falling asleep. Kerr (1991), on the other hand, suggests that DWA might be independent of fatigue or drowsiness and instead may simply be an attention or even memory lapse. The occurrence of failing to remember what happened on the road during a longer time episode is also called the “time gap experience”, as has been proposed by Chapman et al. (2005). The interpretation of DWA as a reduction in vigilance has been made by Schulz (2006).

Then again, some authors keep hold of the assumption that DWA is clearly linked to fatigue and
impending micro sleep attacks. Horne and Reyner (1999) describe DWA in the context of fatigue. Sagberg (1999, 2005) sees it as a precursor to falling asleep, but adds that even well rested drivers may experience sleep-related states like DWA under certain conditions, possibly without a preceding phase of subjectively experienced fatigue.

We see DWA as an important precursor of falling asleep and claim that this state can be described as a drowsy interval between waking and sleeping. DWA might result from the need to keep the eyes open in an important task, while at the same time feeling very sleepy. It might be correlated to a reluctance to discontinue driving despite the feeling of being tired. Drivers might be able to steer subconsciously, but fail to notice relevant changes in the traffic situation. This is the reason DWA poses a serious threat: drivers are unaware of their state until a striking incidence on the road bears down the trance. This is a serious safety hazard and can result in a road accident.

1.2. Own studies

In an earlier study we found evidence that DWA is a likely contributor to sleep-related accidents (Karrer et al., 2005a). We believe that the phenomenon can be induced by repetitive visual stimuli experienced on long, monotonous journeys on straight, flat, featureless motorways (e.g. Thiffeault & Bergeron, 2003). As has been stated by Galley and Churan (2002), people can learn to keep their eyes open under certain circumstances and carry out necessary activities to some degree while actually sleeping. In our view, DWA is clearly linked to fatigue and drowsiness.

The aim of a series of experiments we carried out in a driving simulator was to analyse different fatigue states of drivers with the purpose of developing an algorithm for driver fatigue monitoring.

In first test drives in a driving simulator in 2002, some drivers left their lane with their eyes wide open. In order to learn more about this phenomenon, we developed a classification system including definitions for DWA and micro sleep events. In a large follow-up study in 2003 we systematically documented events we recognized as DWA in a video analysis. We found (moderately) high correlations to saccadic parameters, which partly differed from eye movements and blink behaviour preceding micro sleep events (Karrer et al., 2005a). With an increasing number of DWA events per minute, the mean saccadic amplitude and the mean saccadic duration decreased. This might correspond to the glassy stare of drivers experiencing DWA. Conversely, we found increasing saccadic amplitude with the increasing number of micro sleep, maybe as a result of reorienting after the occurrence of micro sleep. In respect of risk factors, we found a connection of DWA to young, male drivers. We also found that professional drivers show less micro sleep, but more frequently DWA events (Karrer et al., 2005b).

1.3. Purpose of the current study

The main purpose of this study was to evaluate the relation of DWA to the occurrence of micro sleep. Results will help to find out about the still unresolved connection of fatigue and DWA. The occurrence of DWA as an antecedent of micro sleep might explain why drivers continue their drive even in a state of considerable sleepiness.

Within the scope of research concerning driver fatigue monitoring an analysis of the characteristics of DWA can contribute important additional information on a phenomenon. We rather want to examine whether DWA is a fatigue-independent phenomenon of attention decrease or whether it is related to severe drowsiness. Thus we assessed changes in subjective alertness
and blink behaviour preceding a DWA or micro sleep event compared to wakefulness.

2. Method

2.1. Participants
Participants were recruited from the student population at the Technische Universität Berlin and from volunteers enlisted in a database of the department of Human-Machine-Systems. A total of 38 participants consented to two test drives in a driving simulator. Based on the elimination of participants because of data recording problems, a total of 27 participants (16 male and 11 female) with an average age of 27.4 (S.D. = 5.4) were actually used for the subsequent analyses. Participants were compensated with 10 Euros (per hour testing) for 45 min of briefing and questionnaires, 5–10 min of familiarisation with the driving simulator and approximately 2 h of actual test drive by day time and 2-3 h of actual test drive at night time.

2.2. Setting and data collection
The driving simulator used in this study consisted of a real car (VW Bora) with a screen in front of it. Sounds and vibration gave drivers a more realistic impression. Video cameras were mounted in the car to record front and side view of the driver (25 Hz recording rate). For the collection of eyelid data a video-based sensor-system (bright-pupil dark-pupil measurement) was set up on the dashboard and recording equipment was placed in the boot of the car (100 Hz recording rate). The questionnaires used included age, gender, time of getting up in the morning, sleep duration the night before, a series of questions measuring chronotype (Griefahn, 2002), driving related factors (driving license in years, annual mileage, driving style), sensation seeking (Roth, 2003) and sleep disorders.

2.3. Procedure and design
The task for the participants was to drive on a route with monotonous motorway parts and rural, winding road parts with and without other traffic. All participants were instructed to drive as they would usually do. Throughout the entire test-drive, an investigator in an adjacent control room supervised the data recording and dealt with any problems. In addition, all subjects had to rate their subjective alertness on a scale from 10 to 1 every thirty minutes, where 10 corresponded to “fully awake” and 1 to “absolutely tired, need to sleep now”.

In a within-subject design participants attended two test drives, one at day time (9 a.m. or 3 p.m., depending on their chronotype: morning type / mid-range type or evening type) and one at night time (11 p.m.).

2.4. Data preparation
In this study we repeated the method of systematically keeping a record of DWA by video analysis following our tried and tested criteria. DWA was documented if the driver a) stared into space and then his/her head jolted up abruptly or nodded forward, b) started to squint with his/her eyes half-open, c) stared into space and made a driving error or d) if the driver’s eyes rolled back. A micro sleep was identified a) if the driver’s eyes were fully closed (covered pupils) for at least two seconds or b) for less than two seconds, but afterwards his/her head jolted up abruptly or nodded forward. As described here, the difference between DWA and micro sleep is the open or
closed state of the driver's eyes. Time of occurrence and frequency of DWA and micro sleep were calculated, as were their distance and order. In addition, driver drowsiness level according to criteria by Wierwille & Elsworth (1994) was assigned to every minute of the test drive. Eyelid data were processed into variables of blink behaviour, such as 1) blink duration (time between start of closing and end of opening the eye), 2) delay (time from complete lid closure to re-opening) 3) maximum speed of eye lid during closing and opening and 4) lid cleft (distance upper-lower lid in mm). For each 1-minute time frame before a micro sleep occurred, mean and standard deviations of all parameters were computed.

The intervals preceding DWA or micro sleep events were contrasted with the average values during wakefulness according to our video analysis. For subsequent analysis, a one-way ANOVA for dependent measures was applied (DWA / micro sleep / awake state).

3. Results

3.1. Occurrence of driving without awareness and micro sleep

In 12 of the day or night drives the phenomenon DWA occurred in combination with micro sleep. In 7 cases DWA occurred prior to micro sleep while in 5 cases micro sleep occurred first. In 3 test drives only DWA occurred, all of these test drives were conducted during the day. In 10 of the test drives only micro sleep occurred, 9 of it were night drives. Figure 1 illustrates the first occurrence of DWA and micro sleep for the test subjects. Interestingly, the mean time distance between DWA and micro sleep is shorter during the day (Mean= 7.5, S.D. =7.1) than during the night (Mean= 16.08 S.D. =14.57) although it is not statistically significant.

Fig. 1: First occurrence of DWA and micro sleep for the test subjects during the day-drive (left) and night-drive (right)

3.2. Subjective alertness

To find out more about the occurrence of DWA in relation to the subjective alertness, the self ratings (every 30 minute) were interpolated. As shown in figure 2 micro sleep and DWA only occur at stages of lower subjective alertness. Altogether we found an occurrence of DWA at
alertness stage 5 and a moderately higher alertness value in comparison to micro sleep, where the first events occur during stage 4 of subjective alertness.

3.3. Risk factors for driving without awareness
No relation of the following variables to DWA was found to:

1. Demographic factors (gender, age)
2. Driving related factors (driving license in years, annual mileage, driving style)
3. Personality factors (chronotype, sensation seeking, sleeping disorders)
4. Sleep duration

We found a significant negative correlation between time since sleep and first occurrence of micro sleep \( (r = -0.53, p = .011) \). This result reflects the simple fact that the longer the subjects were awake, the earlier they fell asleep during their test drive. Although the correlation of time since sleep and the first occurrence of DWA shows the same tendency, it is not statistically significant \( (r = -0.365, p = .199) \). Two subjects that had a nap between their day and night drive did neither show micro sleeps nor DWA in their second drive.

3.4. Comparison of eye blink behaviour
The results of the one-way ANOVA for dependent measures and the post hoc comparison between the 3 states (awake, DWA, micro sleep) are shown in Table 1. We found significant differences regarding the following parameters: blink duration (mean), delay (mean), maximum speed open (mean) and lid cleft (mean, S.D.). The post hoc comparison between the three states showed significant differences between the states awake and DWA respectively DWA and micro sleep (except for only marginal significance between awake and micro sleep for lid cleft). At the same time the post-hoc comparison did not show any significant differences between the states DWA and micro sleep. The direction of the difference from awake state was the same for DWA and micro sleep.
Table 1: Results of the one-way ANOVA for dependent measures and post hoc comparison between awake/DWA/micro sleep

<table>
<thead>
<tr>
<th>variable</th>
<th>F</th>
<th>df</th>
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<th>post hoc comparison</th>
<th>mean difference</th>
<th>p</th>
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<td>DWA/awake</td>
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<td>delay (mean)</td>
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<td>2,20</td>
<td>.001**</td>
<td>DWA/awake</td>
<td>-37.03</td>
<td>.015*</td>
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<tr>
<td>maximum speed open</td>
<td>17.45</td>
<td>2,20</td>
<td>.000**</td>
<td>DWA/awake</td>
<td>6.13</td>
<td>.006*</td>
</tr>
<tr>
<td>lid cleft (std)</td>
<td>10.226</td>
<td>2,20</td>
<td>.001**</td>
<td>DWA/awake</td>
<td>-1.169</td>
<td>.001*</td>
</tr>
</tbody>
</table>

The relation of mean blink duration and lid cleft is shown in figure 3. While blink duration increases with severe drowsiness, the lid cleft becomes smaller. These well known changes with increasing sleepiness already take place at the stage of DWA and continue during moments preceding micro sleep.

Fig. 3: Average blink duration and lid cleft during wakefulness, preceding DWA or micro sleep. While the difference between awake and DWA is statistically significant (see text) in both cases,
the difference between DWA and micro sleep is not.

4. Discussion

The main objective of the study was to examine the connection between DWA and fatigue. Furthermore, we analysed the triggers of DWA. Regarding the latter, we could not find risk factors for the appearance of DWA, maybe due to our rather homogeneous sample.

However, we did find support for our assumption that DWA represents an intermediate phase between wakefulness and severe sleepiness. DWA often precedes micro sleeps and occurs more frequently during the daytime, whereas micro sleeps are shown prominently at night. We observed that DWA occurs during stages of lower alertness indicated by subjective ratings. Most notably, we found fatigue-related changes in blink parameters preceding DWA. Differences between wakefulness and DWA and between wakefulness and micro sleep both are significant, but the difference between DWA and micro sleep in all cases is not. Thus, while both events reflect a stage of drowsiness that is clearly distinguishable from being awake, the physiological changes from DWA to micro sleep are only gradual. The apparent distinction, the open eyes, does not represent a substantial difference in a person's general activation level.

4.1. Conclusion

On long journeys professional drivers are often faced with the hazard of falling asleep behind the wheel. While micro sleeps are nowadays considered highly dangerous in both accident research and public opinion, DWA may still be regarded as a rather harmless 'time gap experience'. Our findings suggest that DWA does not reflect a simple attention shift, but is closely related to severe sleepiness and should be part of public education. Hence, as soon as a driver becomes aware that he was just driving unaware, he should be awake to the fact that falling asleep is most likely following soon.

References


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