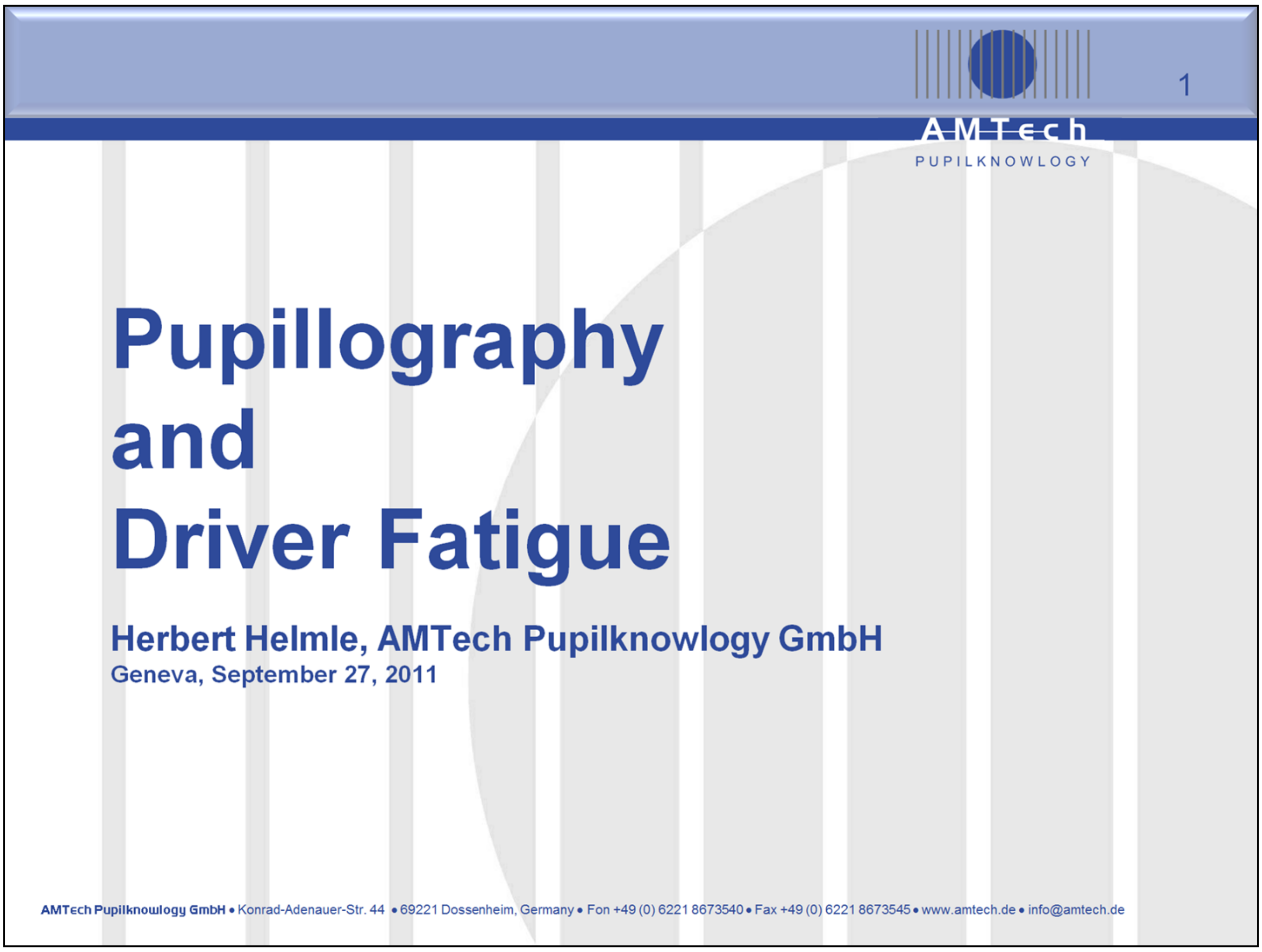


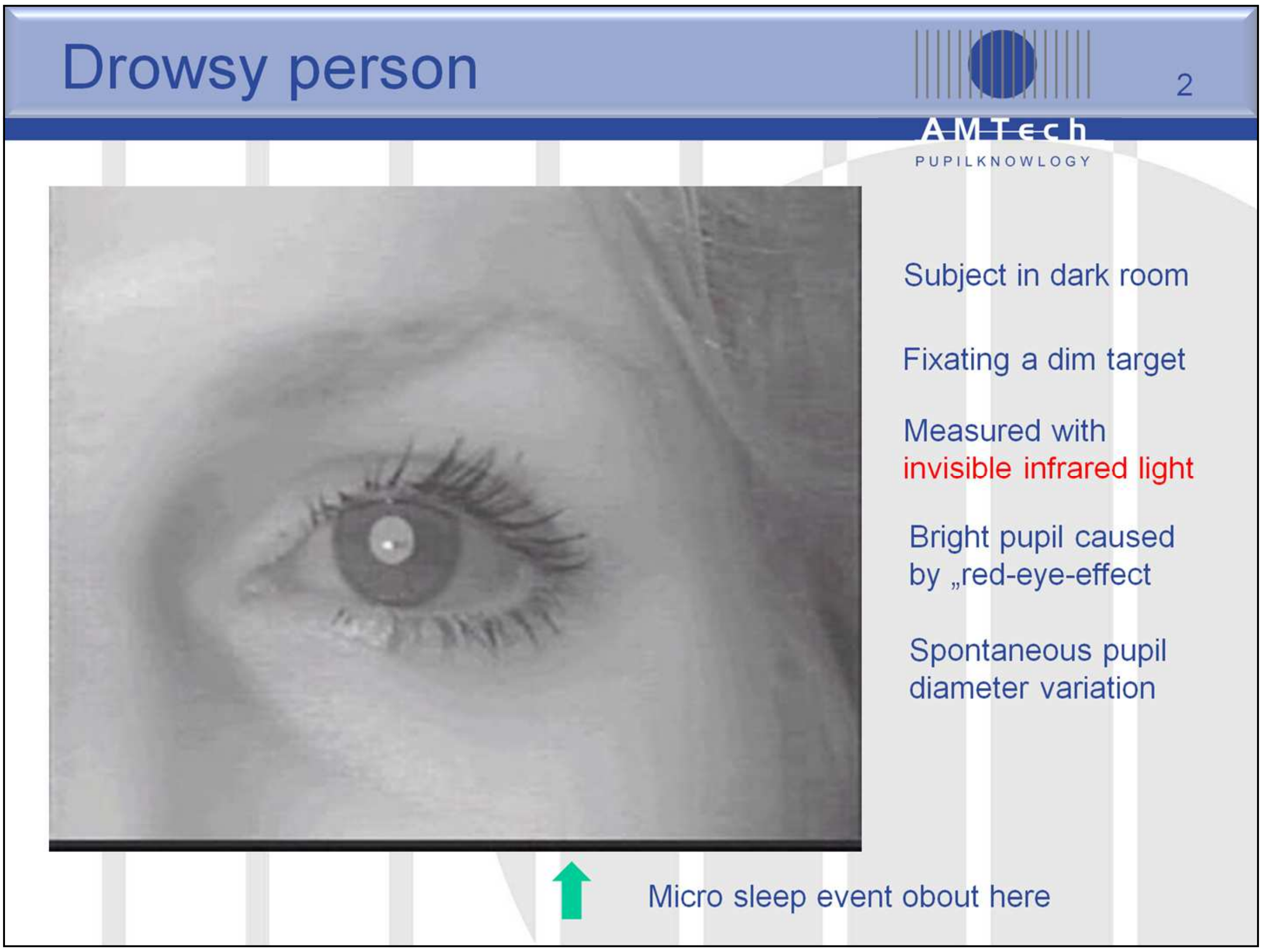
Author:

Dr. Herbert Helmle

AMTech Pupilknowlogy GmbH
Konrad-Adenauer-Str. 44
69221 Dossenheim, Germany

Fon +49 6221 86735 40
Fax +49 6221 86735 45
info@amtech.de

www.amtech.de



For some it might be surprising that fatigue has something to do with the pupil, respectively pupillography.

To illustrate this, please pay attention to this short video:

- This subject is sitting in a dark environment

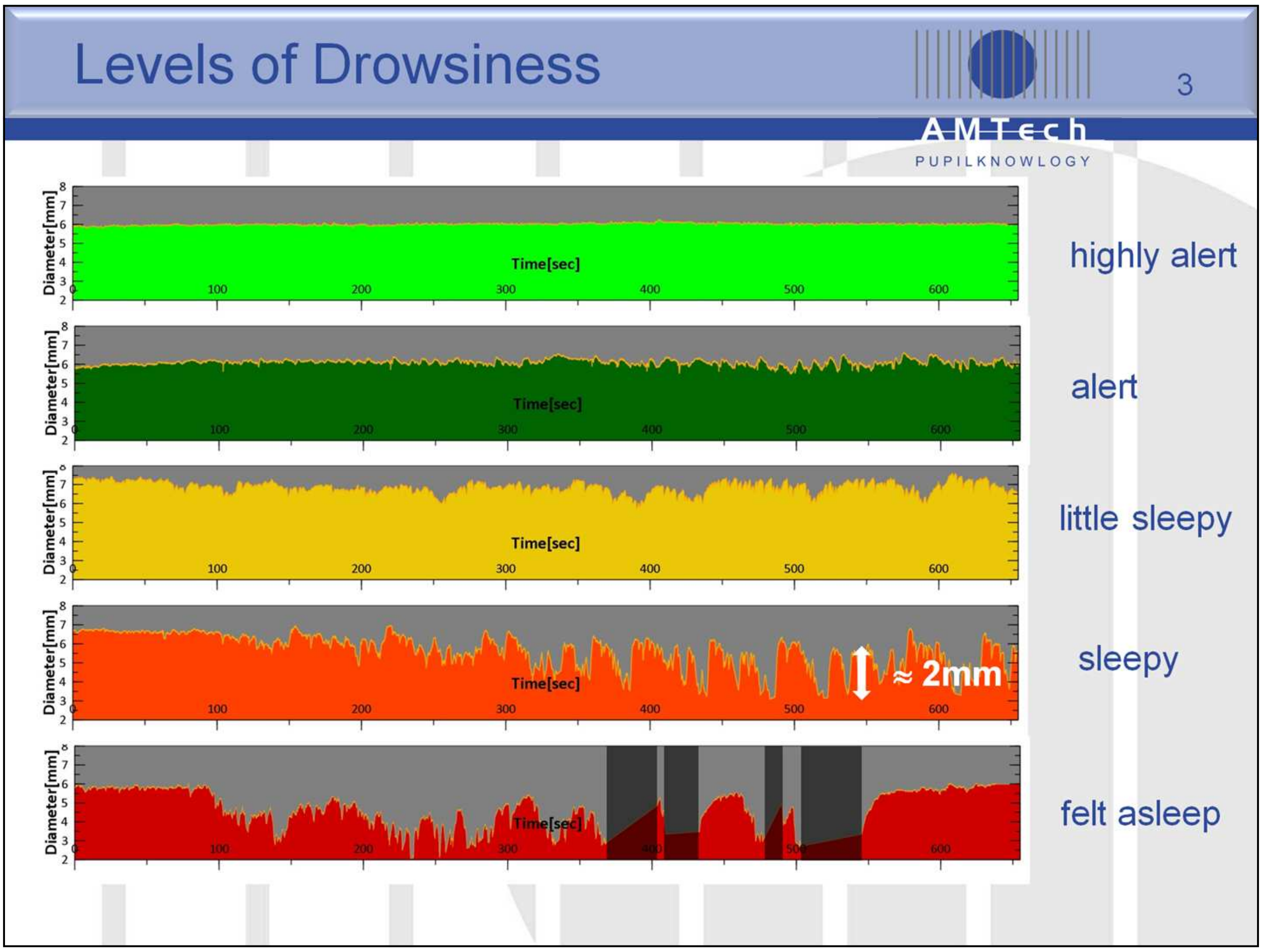
- Fixating a dim target

This video is taken with invisible infrared light

The bright pupil is caused by the s.c. red-eye effect, which is light scattered back by the retina. Because we use here monochrome light and a black and white camera, the pupil is therefore not red, but white.

Watch the spontaneous and involontary pupil diamater changes in this very montoneous and boring environment. This s.c. fatigue waves or pupillary unrest indicated increased sleepiness.

In the second half of the video one sees a micro sleep event of several seconds, where the eye is almost closed and the pupil diameter rather small. This small pupil indicates a decreased symathetic activity and an inreased parasypathetic nervous activity.



When sleepiness waves, like those shown in the video are drawn in a graph of the pupil diameter in millimeters, over time in seconds , it looks like this:

With ongoing time the pupillary unrest increases. The fatigue waves shown in the video, comply with the second half of the graph.

One could argue : sitting in a silent dark room triggers sleepiness anyway. But this is not true.

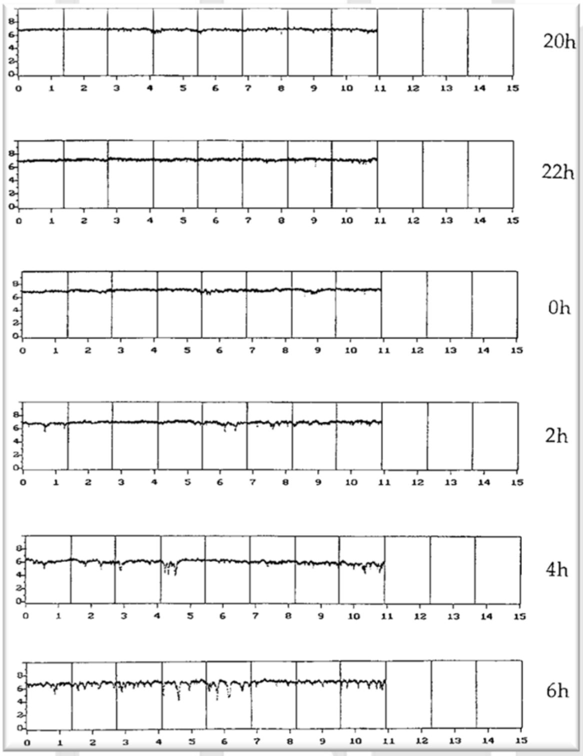
The dark green example is the results of an alert subject. Here the strong changes of sleepiness waves are not observed. There is only a minor affect at the end. Naturally , all the measurements were obtained under identical conditions.
Now some more examples:

In respect to these fatigue waves one can find something in between. This yellow graph is a borderline result, and the light green example in the top graph is a highly alert subject.

Finally the bottom graph: This subject felt asleep after a period with large sleepiness waves. The sleep periods are indicated by this overlayed grey shadows. These are examples of different people in different states of sleepiness.

Effect of sleep deprivation

4

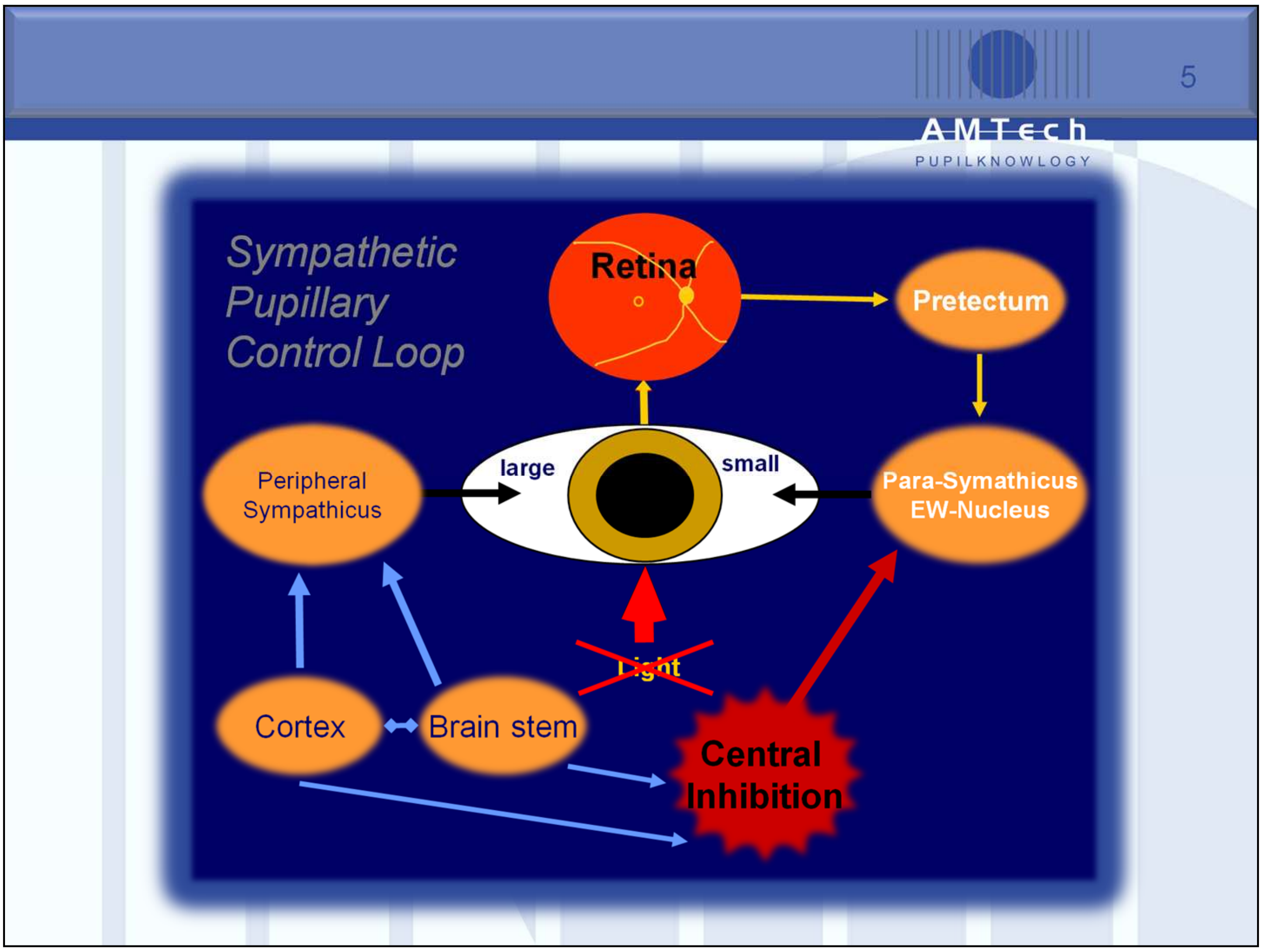


These states of sleepiness are found in a single subject as well.

This slide shows the increasing sleepiness waves in case of sleep deprivation of a single person.

These graphs are measured beginning at 8 o`clock in the evening till 6 am the next morning in steps of two hours from top to bottom.

One can see the slow increase of the pupillary unrest with time, caused by sleep deprivation and an increasing sleep deficit.



Some comments about the physiology of this effect:

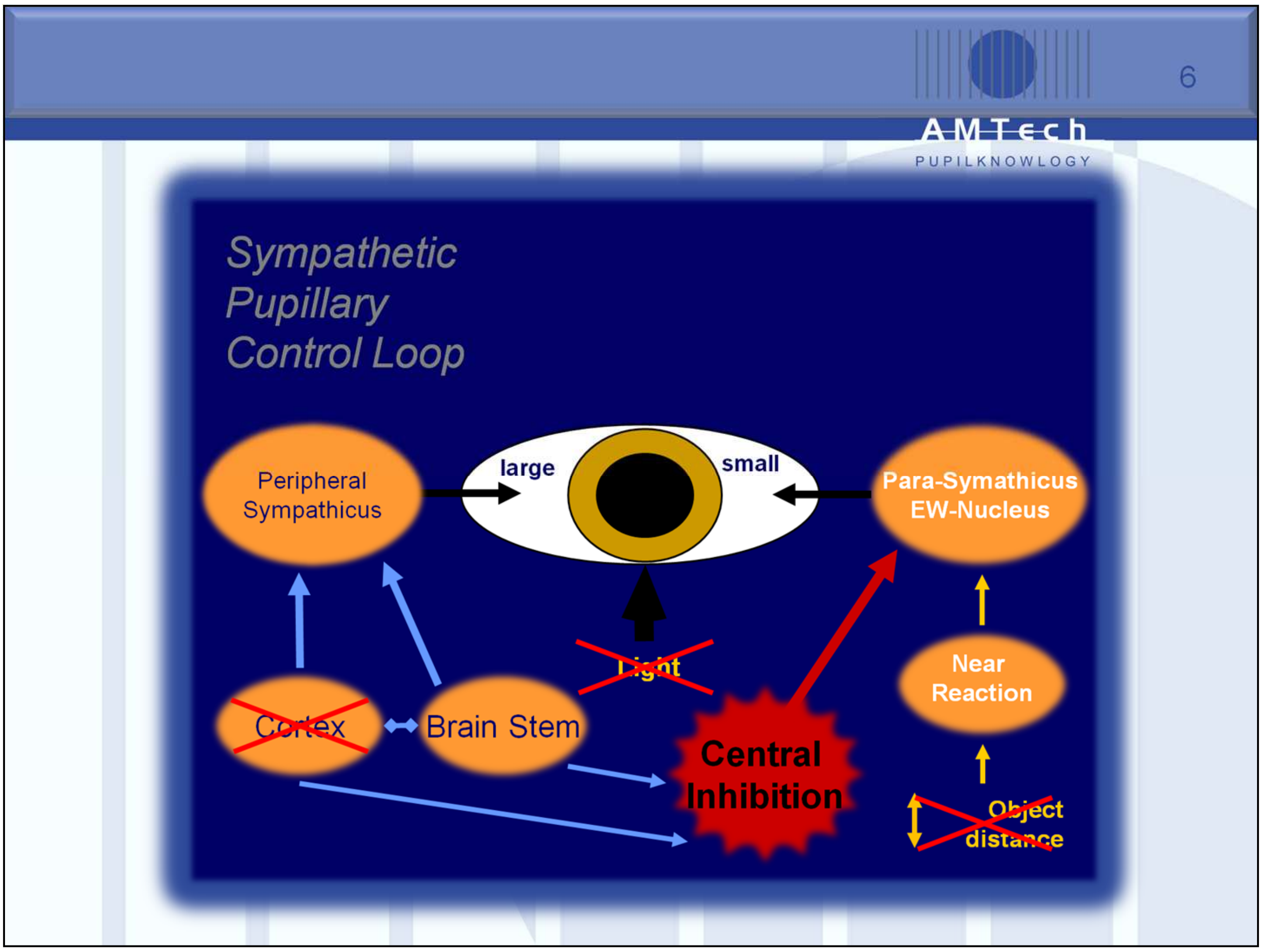
The pupil is driven by two elementary nervous systems. The sympathicus increases the pupil diameter, and the parasympathicus decreases it. This is important in this place because several systems effect the pupil diameter.

At first the pupil light reflex must be considered:

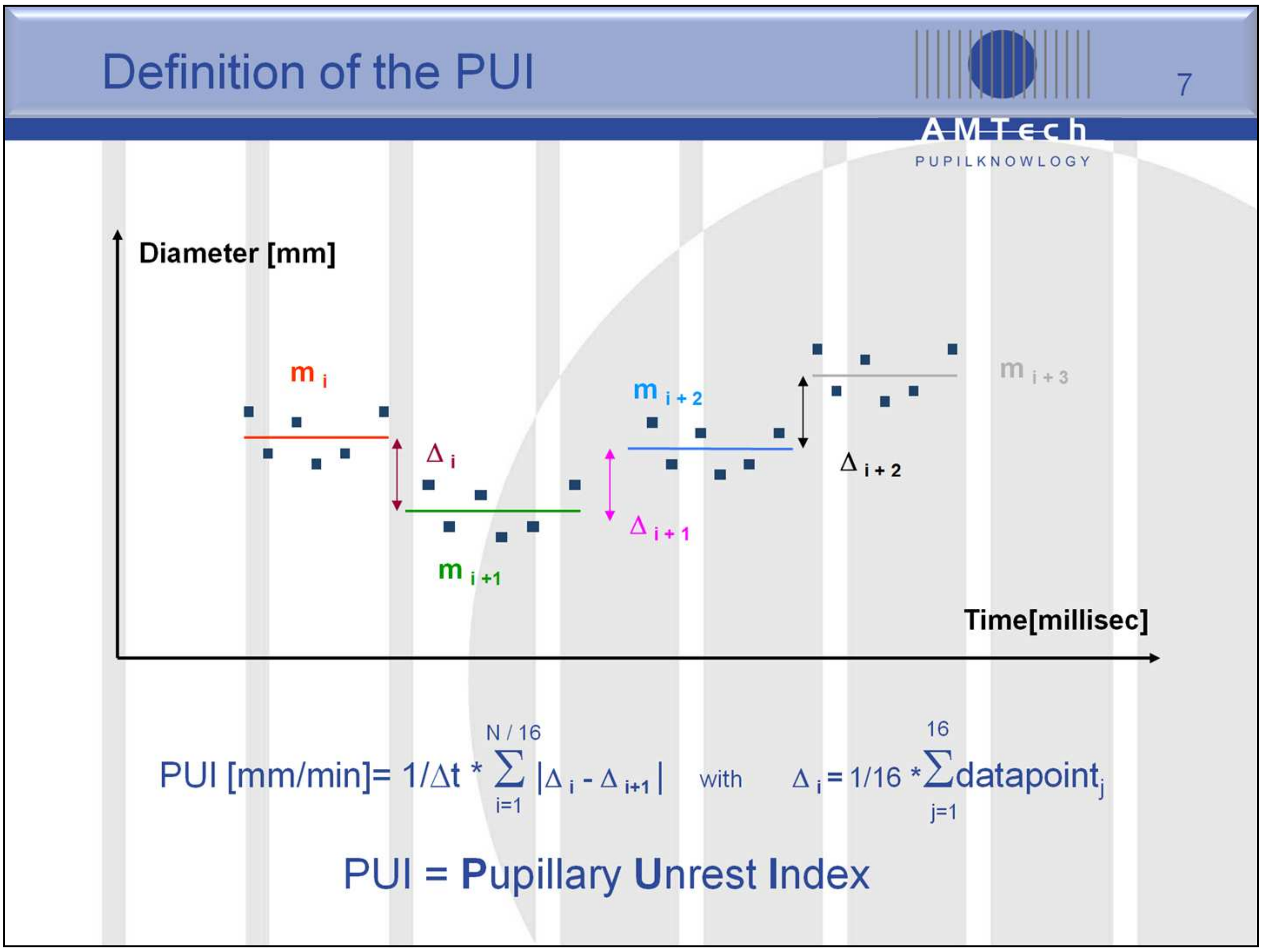
When light reaches the retina through the pupil, the pupil diameter decreases of course.

Consequently any light intensity change must be avoided . Then the fatigue waves are not disturbed by the light reaction.

Additionally , only in darkness one has a large pupil and the pupil is enabled to perfom this fatigue waves.



A less known effect is accomodation. When your eye focuses on a certain distance, then at first the pupil diameter decreases , in order to increase the focal depth of the eye. This is basically the same as in any camera.
Therefore the fixation distance must not be changed during the test ; then the pupil stays large and unaffected by accomodation. Cortical effects on the pupil, which are oberserved while doing mental arithmetics, for example, are rather small compared to the effect we are interested in here. The sleepiness waves have, as seen, an amplitude of up to several millimeters, wheras cortical pupillary effects are in the range of a few tenth of a millimeter and even much smaller. Therefore, when any light reaction is excluded and accomodation and cortical effects can be neglected, then with pupillometry the basic ,so called, central nervous activation of the brain stem is observed. Sleepiness indicating parameters of EEG signals alter synchrone with pupillary unrest. This proves the idea that sleepiness waves reflect the psysiological state of central nevous activation. The sympathicus and parasymathicus do not interact directly against each other, like antagonistic skeletal muscles. In this control loop is the s.c. central inhibition in between. This central inhibition causes this stochastic appearing fatigue waves. Of course these fatigue waves can only be observed, if the pupil is large enough to achieve it. Below about 2 to 2.5 mm of pupil diameter these fatigue waves can not be observed any more. Darkness is therefore sufficient for these kind of measurements.



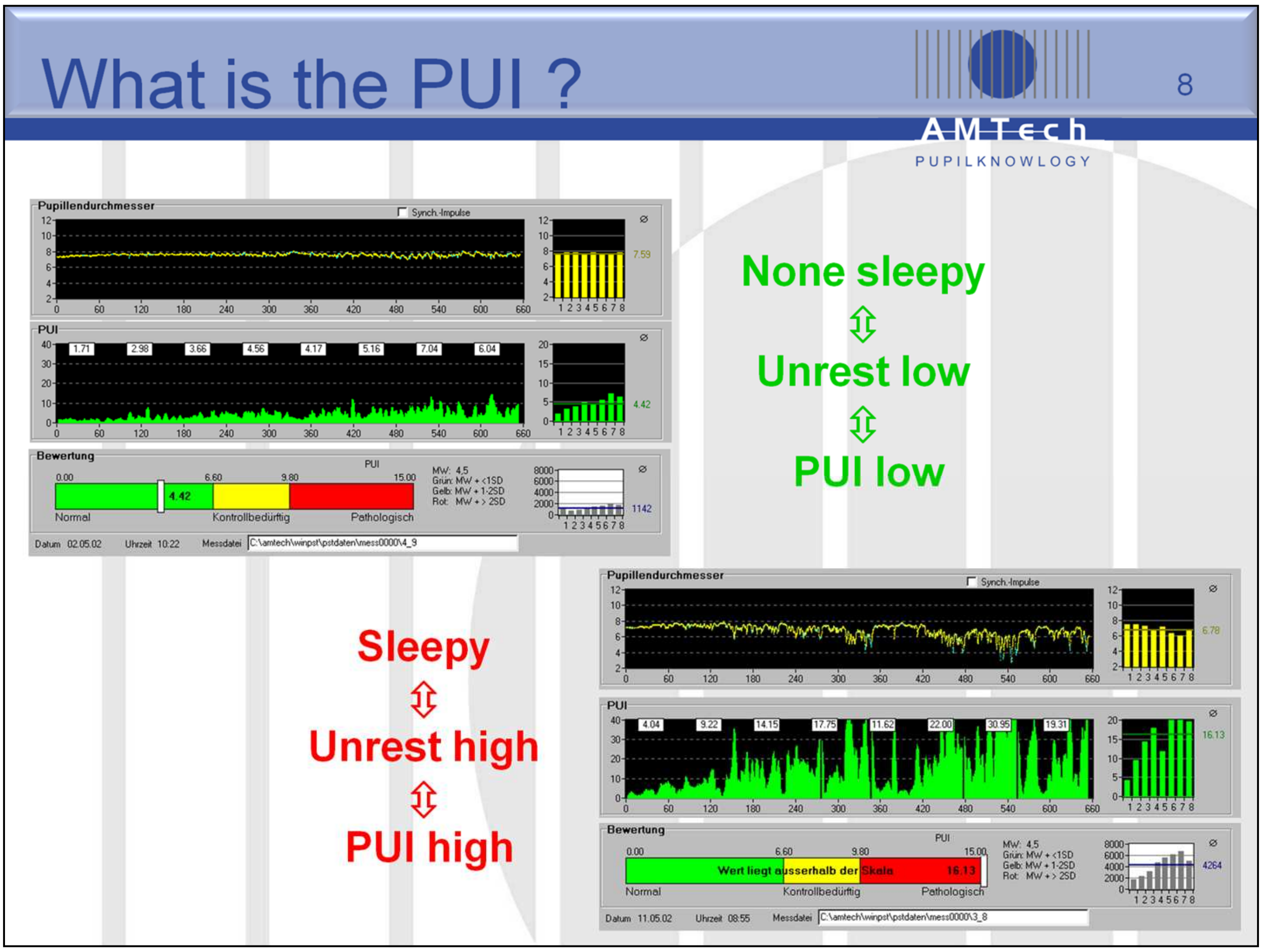
How are these fatigue waves quantified.

The target parameter is the variation of the pupil diameter, not the diameter itself.

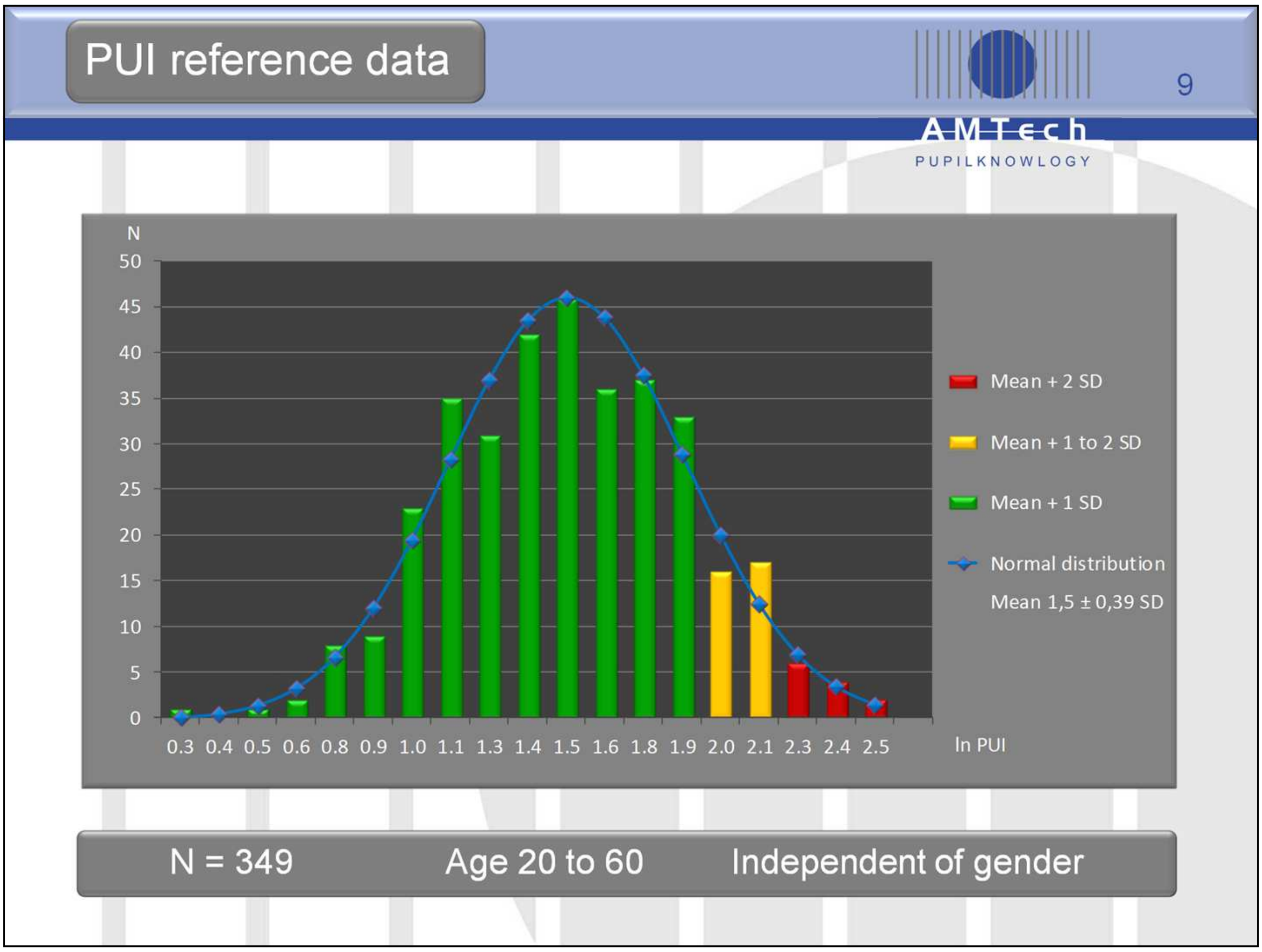
What is calculated is a parameter called PUI, which stands for pupillary unrest index . The pupillary system is a strong low pass filter with a cut-off frequency of 6 Hz. A sampling frequency of 25 Hz is therfore sufficient.

From the pupil diameter data sampled with this rate, at first means of 16 consecutive points are calculated. In a second step the absolute values of the differences of this means are accumulated.

Thereby a decreasing as well as an increasing pupil diameter contribute to the PUI.



This two examples illustrate the PUI in an alert and a sleepy subject. The pupillary unrest is low in an alert subject, and therfore also the PUI, whereas in sleepy subjects the pupillary unrest is high and the same with the PUI.



For the PUI reference data are available.

They are based on a group of 349 alert subjects, aged 20 to 60 years, men and women. These data are recorded in the morning between 8 and 12 am. The measuring time was 11 minutes.

The logarithm of the PUI leads to this almost normal distribution. The alert, or green, region is by definition the mean of this distribution plus one standard deviation.

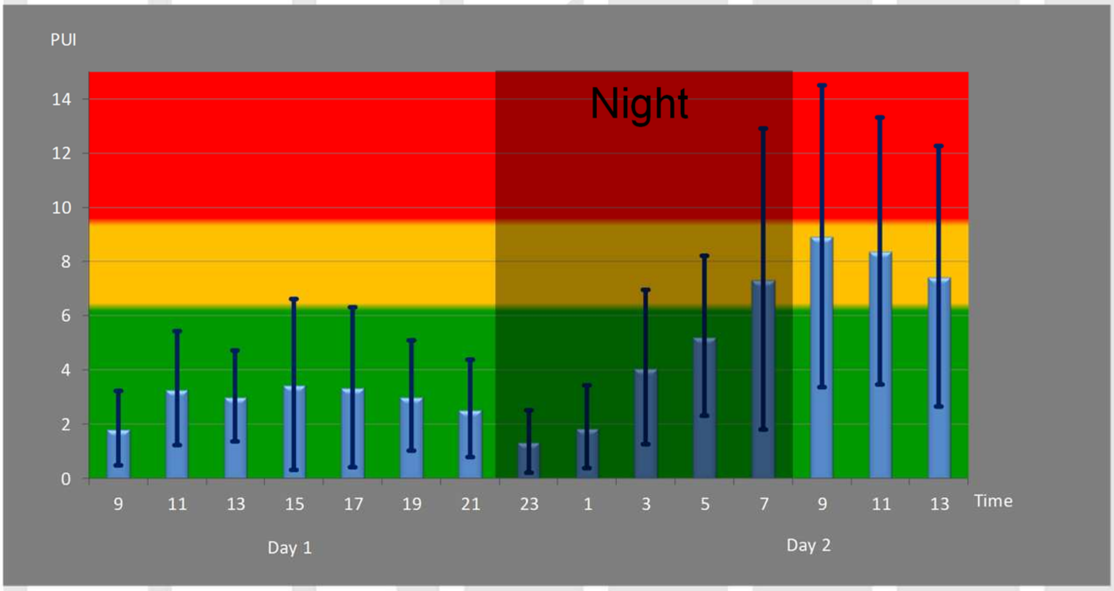
The borderline or yellow region are the results of the mean plus one to two standard deviations.

A subject is sleepy, and marked in red color, if the result is higher than the mean plus two standard deviations.

All following results use these thresholds and colour codings.

Sleep deprivation experiment

10



This is the result of a sleep deprivation experiment over 36 hours. The night time is marked with the black shadow.

One can see the well known slight rise of sleepiness in the afternoon, a time where most of us drink their coffee or tea.

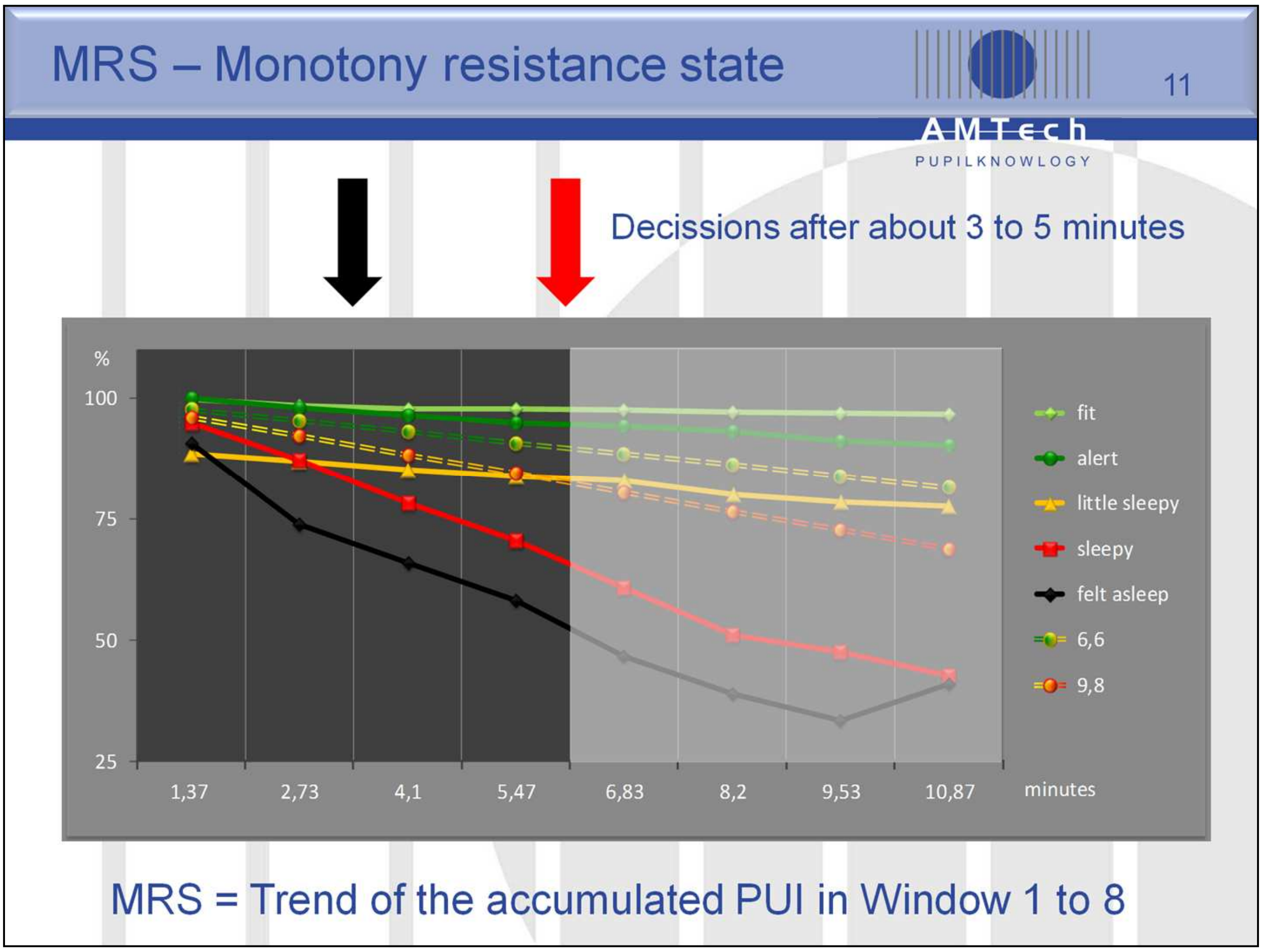
Remarkable is the minimum in the evening and the steep increase during the night.

In the morning of day two the sleepiness decreases even without any sleep during the night.

Thats is we all experienced already at some time or the other. That we feel better in the later morning even after we spend the night waking.

This data show that in a normal alert person the PUI varies according to the normal circadian rythm during the whole day in the green and sometimes a little bit in the yellow region, but never in the red region.

Therefore any result of a PUI higher than 8 mm/min is a positive or pathologic result, independent of age, gender, or time of day.



Now some comments about the question how long must be measured to obtain reliable results.

The so far presented data are measured for 11 minutes.

With the new parameter MRS, we call it monotony resistance state, the measurements can be shortend to about three to five minutes.

The dashed lines are the thresholds between the green and yellow and the yellow and red region, respectively.

The MRS is derived from the reference data and is an accumulated PUI and shown here for the previous examples. Obviously the decission that a person is very sleepy (here the red and black line) can be drawn at least after about 5 minutes.

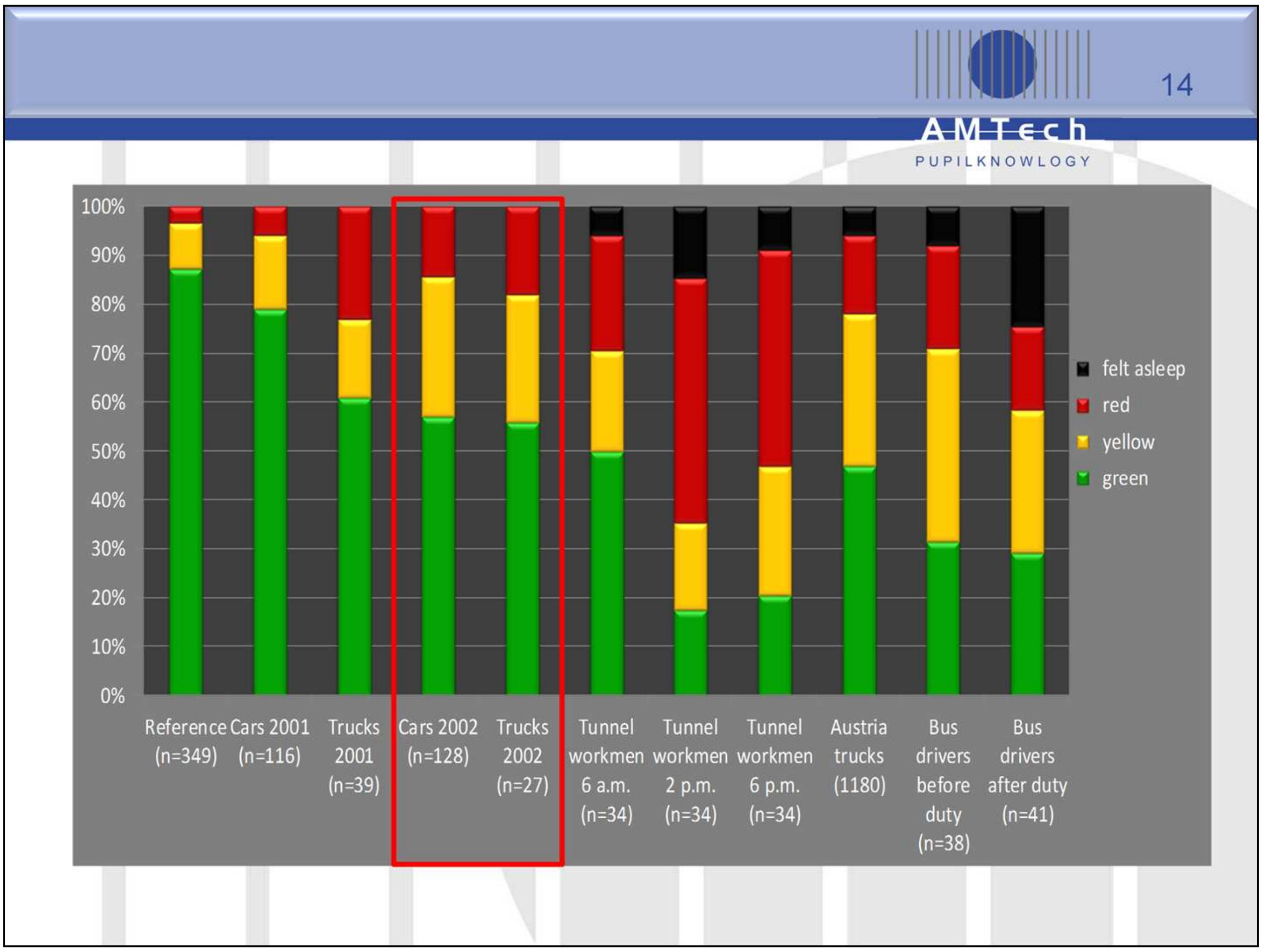
This seems still a long time, but please don‘t forget that we measure vigilance. And vigilance is a slow process. This means, that independent of any technique a little bit of patience is needed to get a reliable result. Compared to other methods pupillography is the most speedy method to measure and to quantifiy sleepiness objectively.

Now to some results of several studies.

The column on the left entails the reference data.

In 2001 and 2002 we made our first road side studies with volunteers at a road house. The car drivers performed a little bit but significantly worse, than the norms to the left.

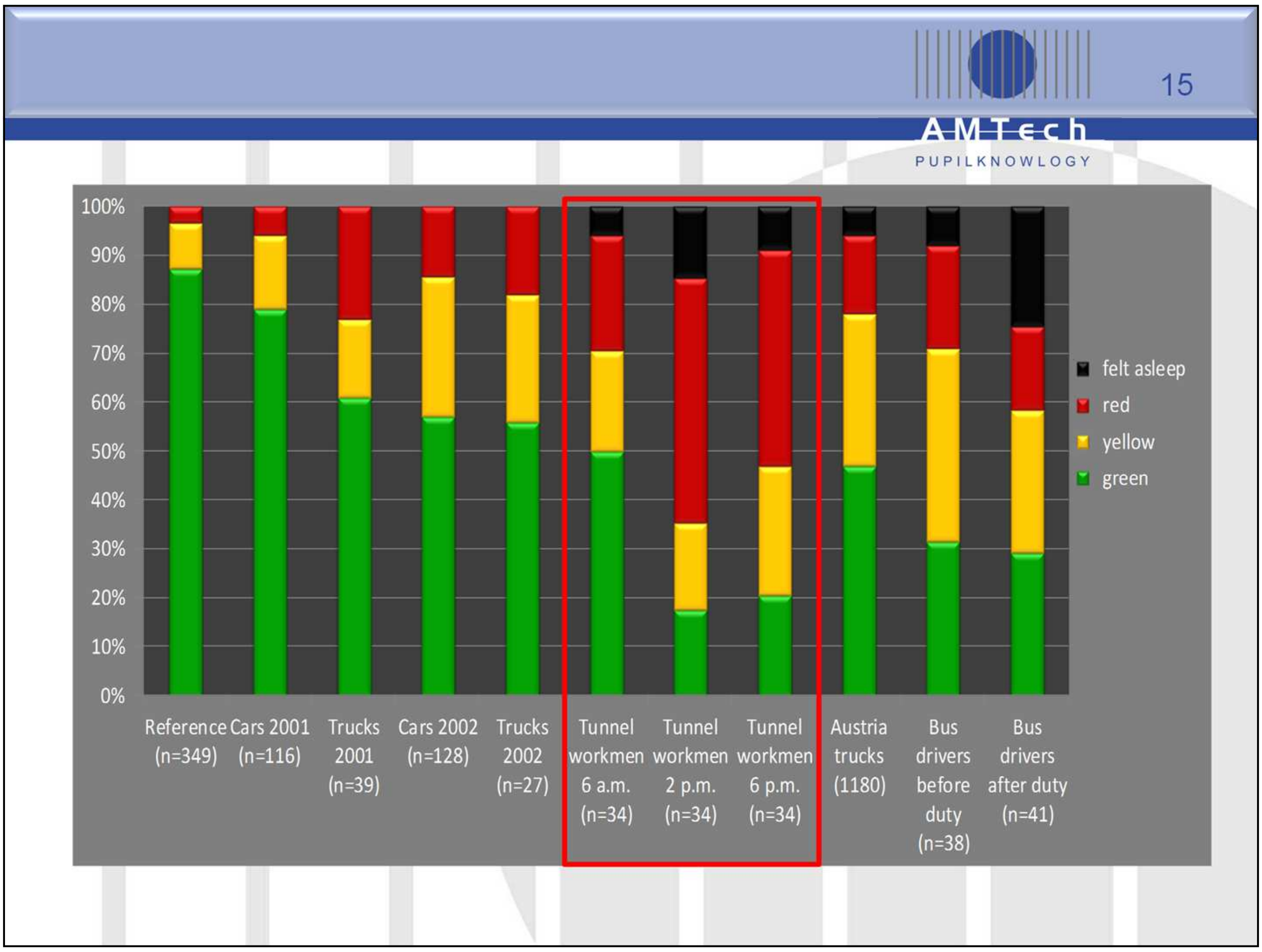
As suspected, the truck driver group consisted of more sleepy drivers, than those found among the car drivers.



In the study one year later this difference disappeared. What was the reason ?

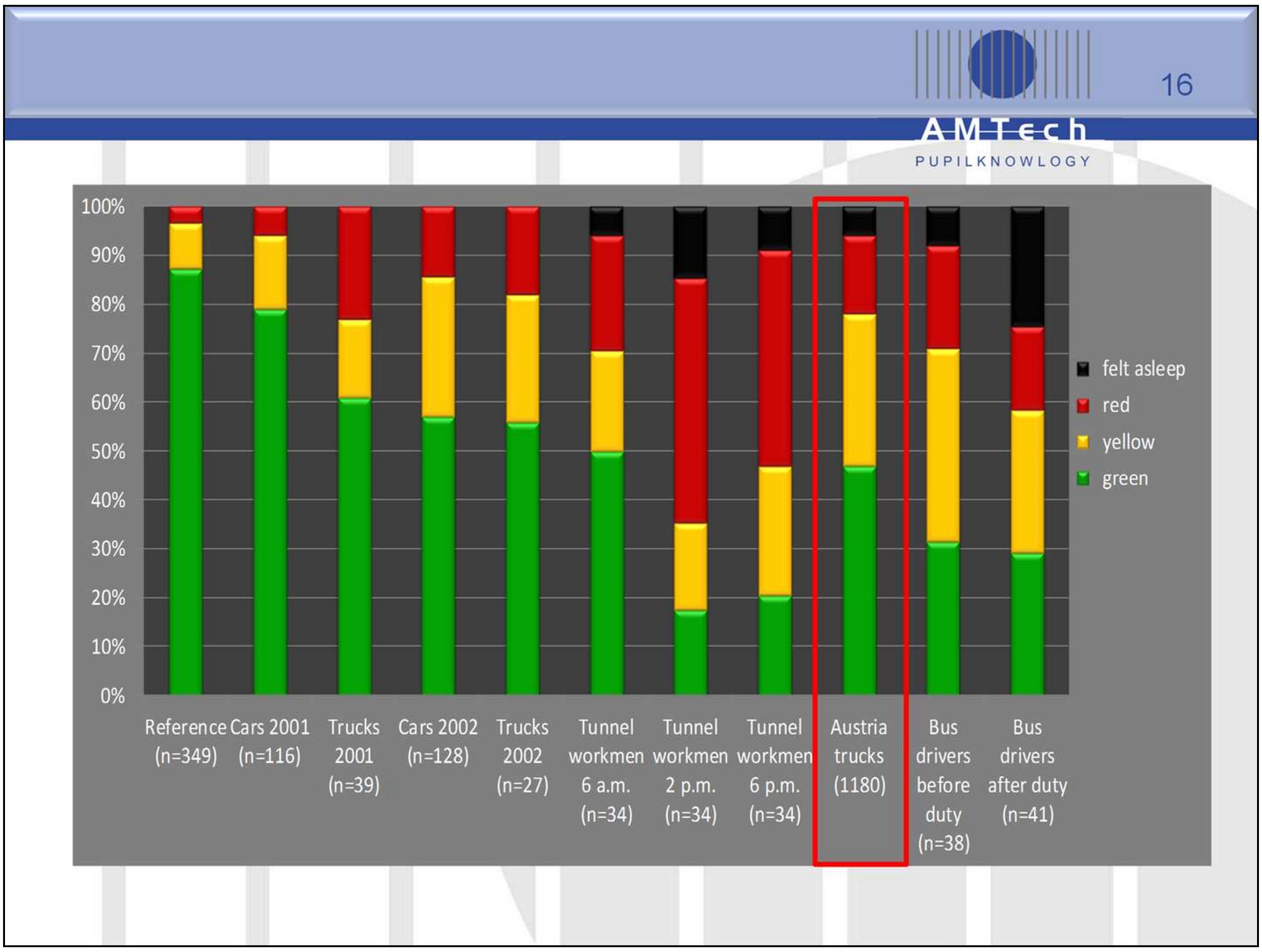
The truck drivers performed as badly like the year before, and the car drivers performed just as bad as the truck drivers.

The reason was, that on the day we tested in 2002 it was awfully hot compared to the year before. Most of the trucks had air condition, but the private vehicles did not. Thus the sleepiness of the truck drivers was about the same as the year before, but not so of the car drivers. They suffered more under the heat and got more tired than the truck drivers did.



The next three columns are results of tunnel workmen in the morning, the early afternoon and in the evening. Remarkable is that some of them are sleepy already in the morning before their duty. The black data indicate subjects who actually fell asleep during the measurement. Only 50 % were rather fit in the morning. They performed even worse at noon, and a little bit better in the evening.

In part can these results be explained also by the really hot temperatures in the tunnel and the hot summer, when this study was performed. Especially the morning data indicate an insuffificient and not refreshing sleep during the hot nights.

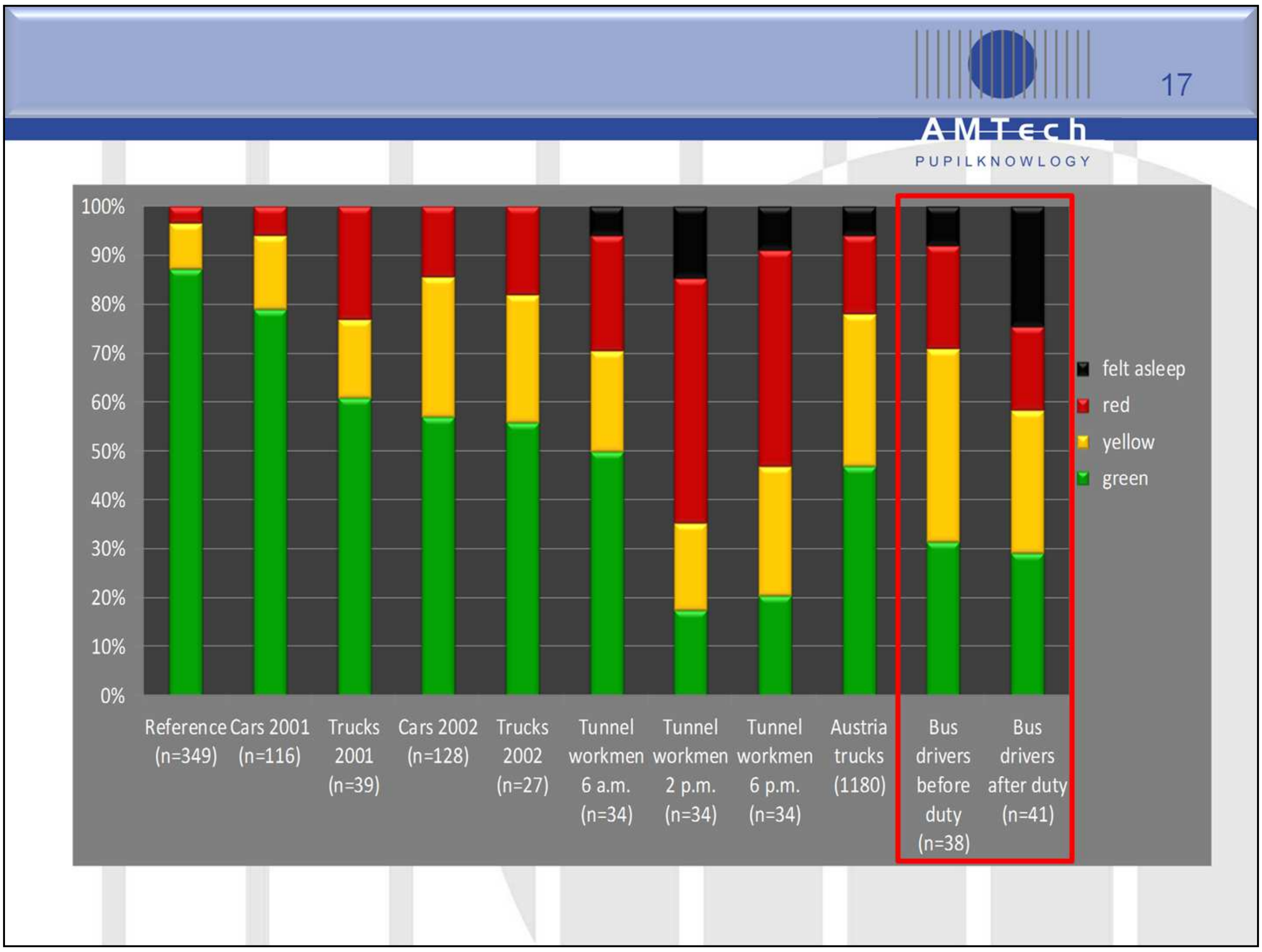


This study is important because of its large number of more than 1100 subjects, and because these data were recorded during normal traffic controls of the police.

Our fear was before, that the presence of the police could influence the results. This were clearly not justified. The results are even worse than of the voluntary truck drivers (in column 3 and 5); 6% of the truck driver felt asleep.

Among the voluntary truck drivers no one felt asleep. This might be the group of drivers with a high sensitivity for the problem of drowsiness. The data of the studies in 2001 and 2002 are most likely biased in a positive sense.

Wheras the police selected the candidates for increased sleepiness, the data where biased towards higher levels of sleepiness.



Finally two columns with data of bus drivers during their normal duty of overnight long distance services. Some of them felt asleep already before their duty. And performed even worse after their ride.

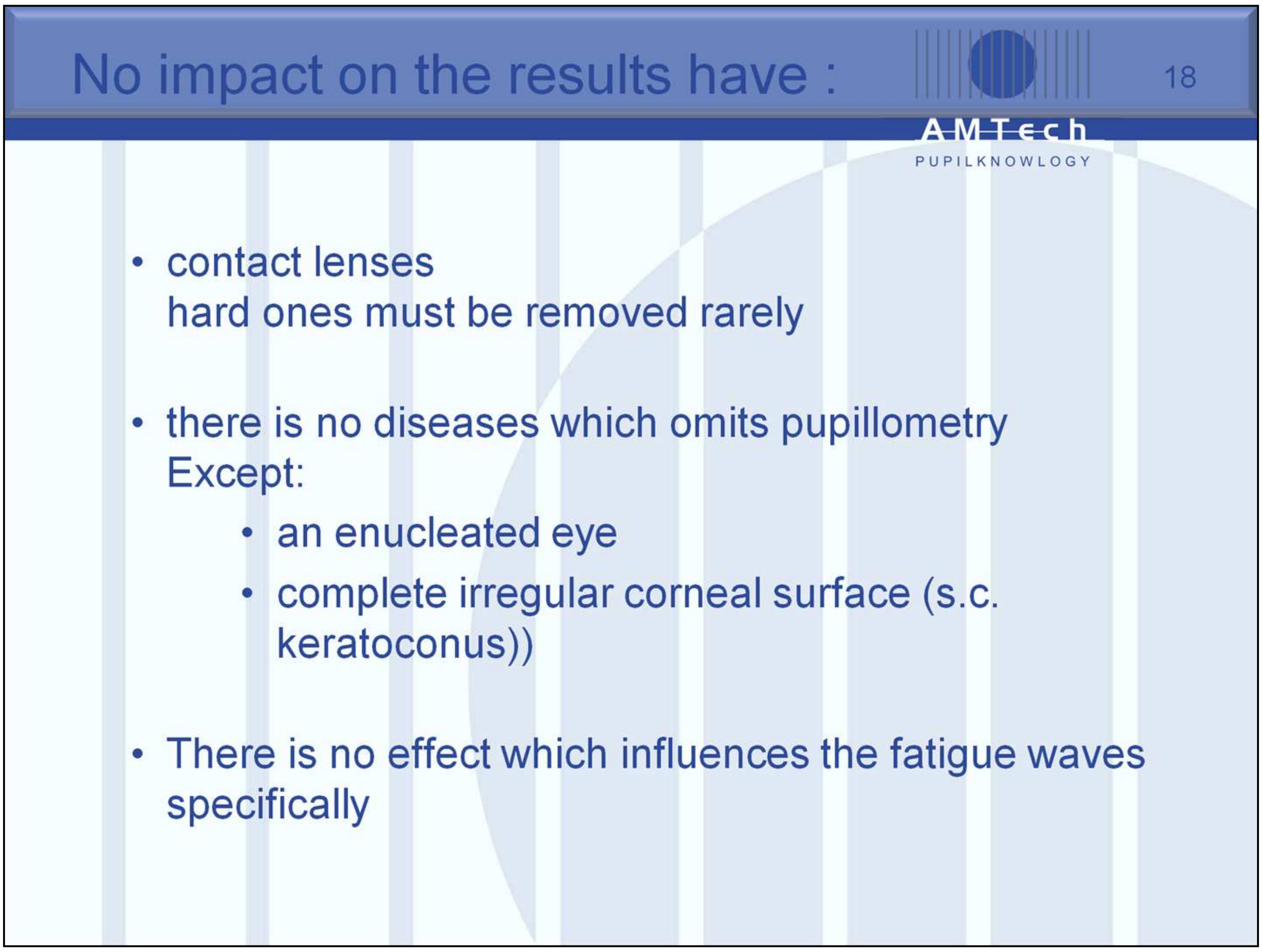
In total :

In all studies an increased number of sleepy people were found compared to the reference group.

In some studies dramatic high levels of sleepiness were measured.

One can conclude:

Pupillography is a sensitive and valuable tool for road side measurements of sleepiness.



Some technical additions:

Contact lenses do not cause problems for this technology

Very rarely the hard lenses has to be removed.

There are no deseases or illnesses, one might find in people who are permitted to drive, which could interfere with the measurement.

Pharmacological effects must be considered of course, but there is no drug known, which influences specifically the fatigue waves (except locally applicated drugs by an opthalmologist)

In case of **non ideal** environments

AMTech
PUPILKNOWLOGY

19

like noise, not perfect darkness, police, TV-crews, etc.

- Little sleepy subjects perform better

  but this is not the targeted group

- Sleepy subjects are not, or only minor affected

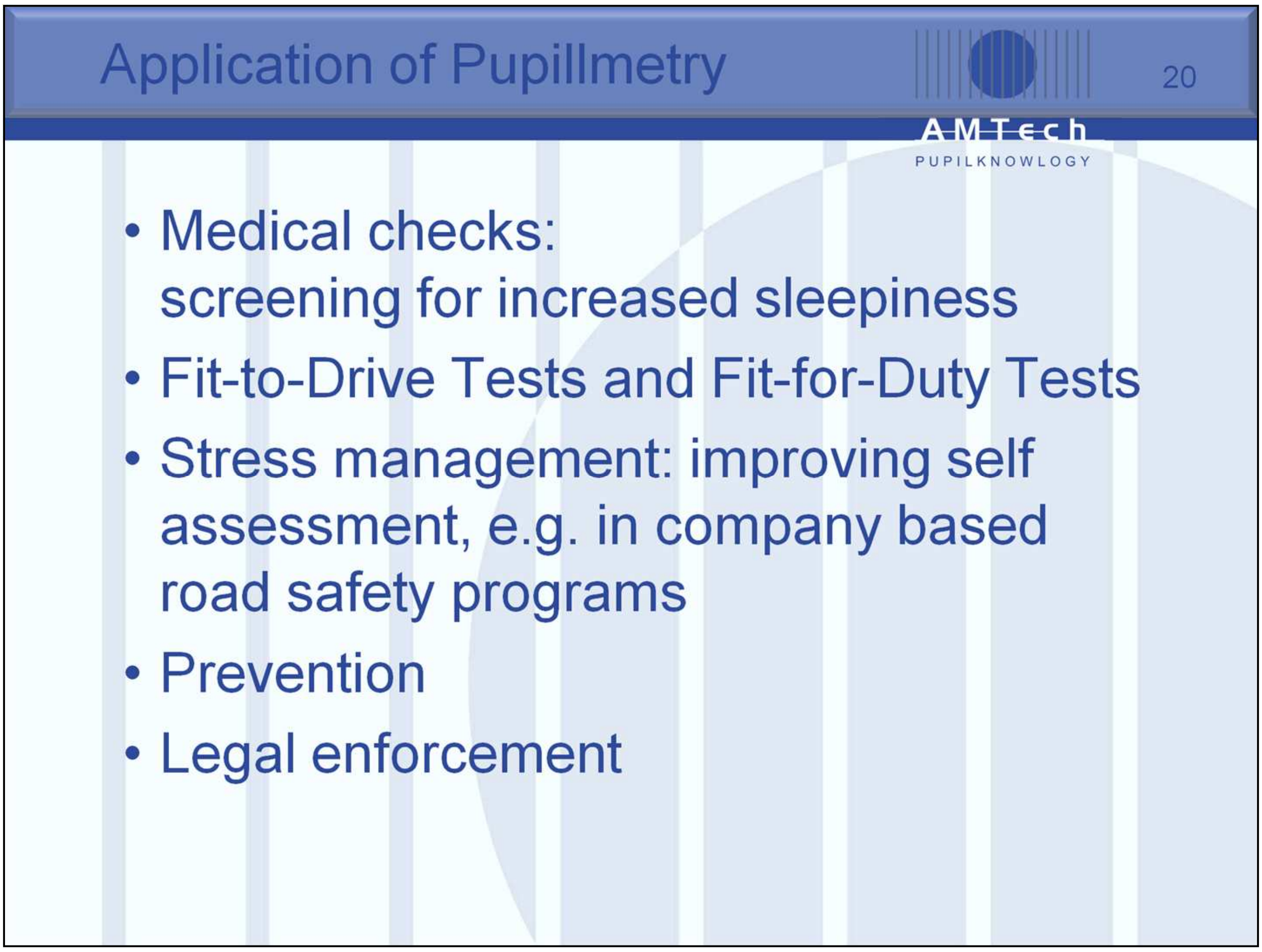
  their sleepiness must be uprated

Conclusion: there are no false positive results !

What happens when pupillometry is performed outside the laboratory. It might be, that slightly sleepy persons perform better, but this is not the target group and does not disturb the usability.

Really sleepy subjects are hardly affected by surrounding noise and residual light. Because of unexpected stimulations in the natural envionment , results of sleepy people might be slightly lower than they should. The traffic safety relevant extreme sleepiness, was not, or only minor affected, by the not perfect measuring conditions. Severe and for traffic safety relevant sleepiness can be detected with this method.

In any case we may conclude that due to stimulation from environment one will never obtain false positive results.



Applications of pupillography to improve traffic safety:

Pupillography allows fast and easy screening for hypersomnia in periodical medical checks of drivers

Pupillography makes objective Fit-to-drive and fit-for-duty tests possible in respect to sleepiness.

And stress management is possible. Recently in Germany a study about stress among professional drives was published. 25% of all professional drivers suffer from acute stress. The problem of stress in respect to traffic safety is the reduced and insufficient self assessment of stressed persons. They do not perceive their actual level of sleepiness correctly.

Pupillography is a reliable tool for prevention and of course legal enforcement.

Contributors to this presentation:

21

Prof. Dr. Barbara und Prof. Dr. Helmut Wilhelm
Steinbeiss Transfer Center und University Eye Clinic, Tübingen

Dr. Hans-Günter Weeß
Sleep laboratory, Klingenmünster

Prof. Dr. Wolfgang Grellner
Institute for Legal Medicine, Göttingen

Dr. Holger Lüdke
Fa. Datinf GmbH, Tübingen

Prof. Dr. Manfred Walzl
Clinic for Neurology, Sleep lab, LSF Graz, Austria

Dr. R. Landwehr
Neurology Clinic Kaiserslautern

Hofrat Prummer, Dr. Schanovsky, Dipl-Ing. Hagen
Land Oberösterreich, Abt. Verkehrstechnik

Prof. Muttray, Dr. Hagenmeyer
ASU Mainz, IAT Stuttgart

Scientists who contributed data to this presentation.

The AMTech Pupilknowlogy GmbH develop and produce three types of somnometer,

- the PSTeco, at the bottom left,
- the PSTxs, at the top left side and
- the F2D Fit-for Duty-Test.

The F²D Fit-for-Duty system is designed especially for road side tests.

It is mobile and very robust .

This system consists of two cases, one with the computer, the imaging hardware, monitor etc,

And a second one with the protocol printer ……

View in 2. Suitcase

24

and stowage room for the video goggles, cables, power supply and other accessories

With a DC power supply the F2D can be employed in any car, like here in the van of our company.

These are the video goggles.

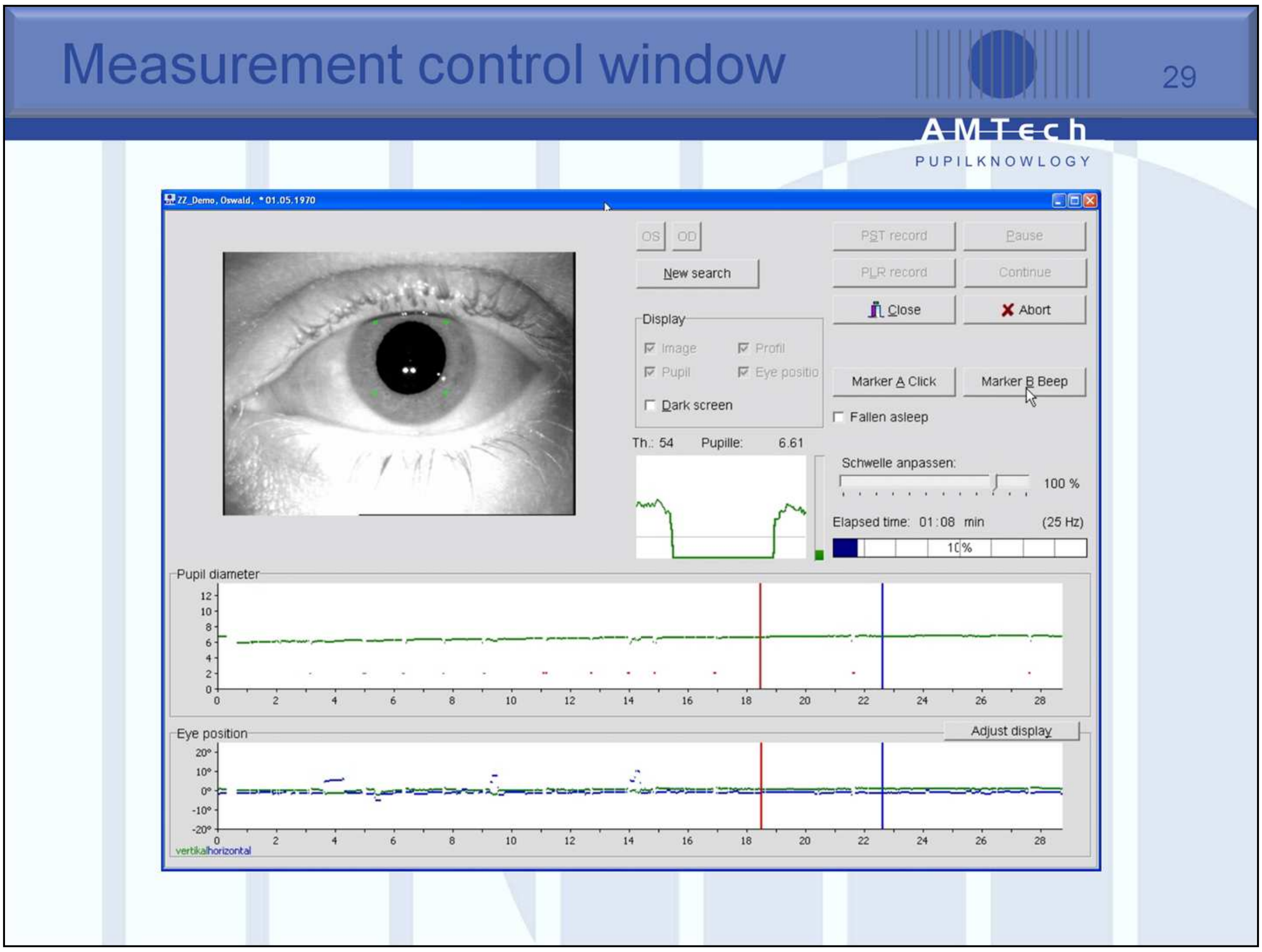
The goggles have two infrared cameras, two infrared mirros, the cameras are inside the boxes at each side. The four magnets hold the cover to darken the inside of the goggles .

The subject sees a dim red light for fixation.

At each side are three knobs to direct the camera onto the eye and to focus the video image of the eye.

For a measurement

- the subject is seated
- the goggles putted on
- the goggles closed with the cover
- and the head set with active noise compensation attached



Measurement control window of the F²D:

Top left:
Control image of the measured eye with marked pupil

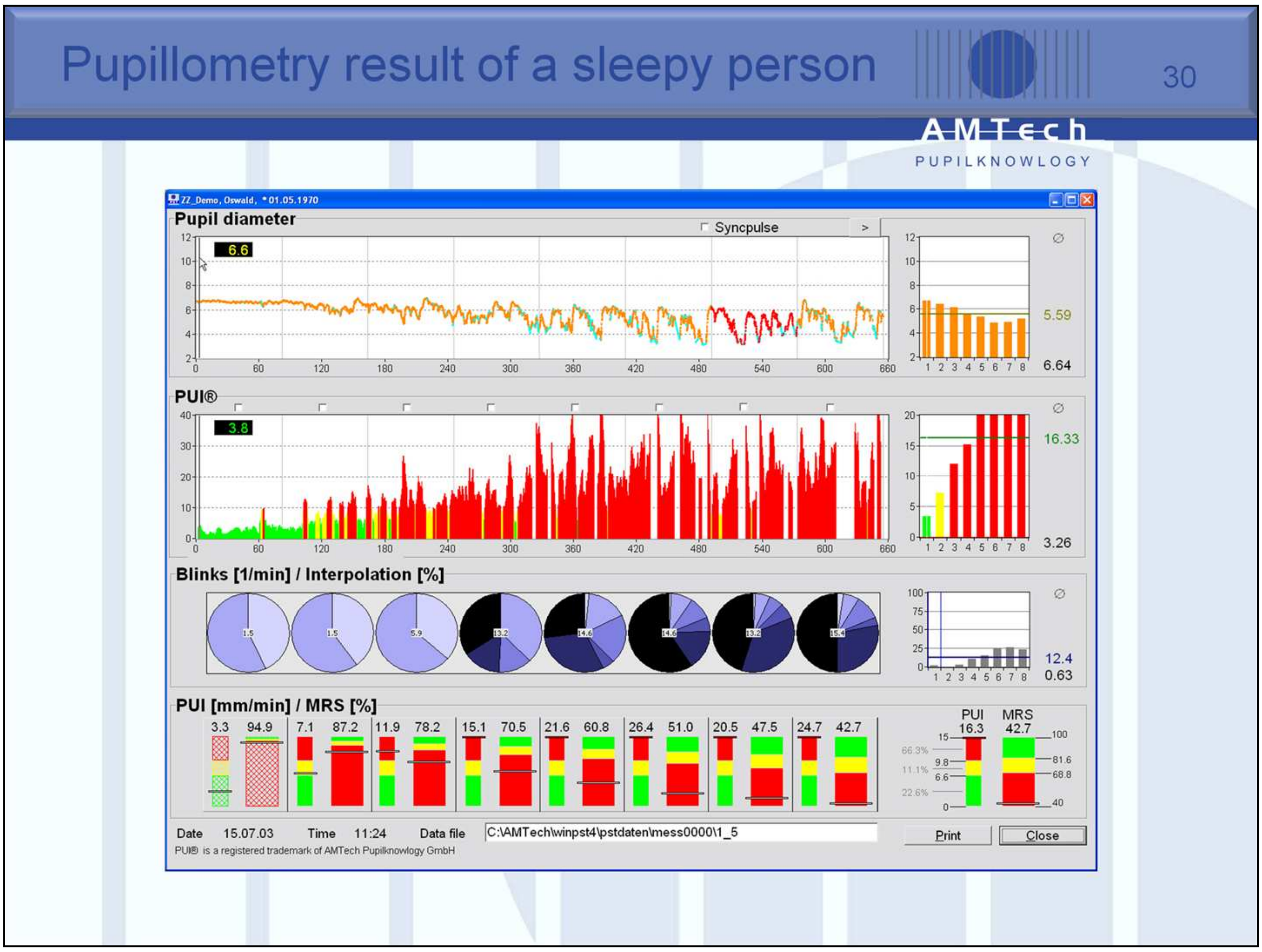
Top center:
Display options radio buttons

Top right:
Function control buttons, horizontal elapsed time bar

Center:
Cross section of the dark pupil and vertical bar: focus contol or PUI estimation

Top horizontal data window:
Pupil diameter with event marker

Bottom horizontal data window:
Horizontal and vertical eye movement with event marker



Result of an 11 minutes measurement of a sleepy person:

Top graph:
Pupil diameter over time in seconds, devided in eight segments; mean data of each segment at the right side

Second graph from top:
PUI as a function of time

Third graph from top:
Evaluation of blinking

Bottom graph:
PUI and MRS for each segment and the overall result to the right