

The Amplitude-Velocity Ratio of Blinks: A New Method for Monitoring Drowsiness

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Introduction

A blink is a brief, reflex-controlled closure of the eyelids that occurs either spontaneously, voluntarily or in response to a noxious stimulus. Each blink begins with inhibition of the tonic contraction of levator palpebrae muscles (LP) that otherwise keep the upper eyelids elevated during wakefulness (1). In addition, orbicularis oculi muscles (OO) then contract to close the eyelids actively. The eyelids open when the OO muscles relax and the LP muscles contract again to elevate the upper eyelids. During most blinks in alert subjects the eyelids do not stay closed for more than a few msec, and the whole blink lasts about 100-300 msec.

In the drowsy state some blinks last longer than 500 msec because the eyelids stay closed for some time, presumably because tonic contraction of the LP muscles is inhibited for longer than normal. Closing and opening of the eyelids is also slower because the strength of contraction of LP and OO muscles is reduced.

In recent years, methods have been described (eg PERCLOS) for monitoring drowsiness from video-camera images of the face and eyes (2). Such methods measure the frequency and total duration of prolonged blinks and other eyelid closures per unit time, typically 1 to 6 min. However, there are other parameters of blinks that these methods do not measure. It is known that, in alert subjects, the peak closing velocity (PCV) of blinks is highly correlated with their amplitude (3). Blinks are not all the same, and the larger the blink the higher its velocity. However, with drowsiness, blinks become relatively slower for the same amplitude.

Absolute measurements of PCV, in mm or degrees/sec, and of A, in mm or degrees, are not easy to make because measurements of the linear or angular distances involved must be calibrated. However, the ratio A/PCV has the dimension of time, not of distance (amplitude) or of distance per unit time (velocity). So long as the measurements of A and PCV involve the same units of distance, their ratio can be derived from uncalibrated measurements.

Aim:

The aim of this investigation was to measure the amplitude/velocity ratio of blinks (AVRBs) in alert subjects and to see how those ratios changed with drowsiness as a result of sleep deprivation. The practical significance of any such changes in AVRB, in terms of the subject's performance, was assessed by a new psychomotor vigilance test, the Johns test of vigilance (JTV), that also enabled eye and eyelid movements to be recorded.

Methods:

The subjects were 12 healthy volunteers (7F, 5M: 19-64 yr). Eight had eye and eyelid movements recorded during 10-min psychomotor vigilance tests (JTV) done repeatedly every hour or so in the afternoon/evening when alert, and again during the night after being awake for 20-24 hr, or alternatively next afternoon after 30-32 hr of wakefulness.

The JTV required a push-button response to a change in shapes lasting 400 msec on a PC screen at random intervals of 5-15 sec. Four other subjects were tested on a STISIM driving simulator for 30 min at a time, several times during the evening and night while awake for 24 hr. One of the latter subjects was also tested at another time with the JTV, as in the first group. All subjects had practice runs.

Eye and eyelid movements were recorded by a specially developed infrared (IR) reflectance method using 50-microsec pulses of IR light every 500 microsec from light-emitting diodes, one pointing at each eye, the reflected pulses being detected by adjacent phototransistors. The small transducers were attached to a light spectacle frame. The effect of environmental light measured just before each pulse was subtracted from the output. The pulse height (position) and the change in pulse height per 10 msec (velocity) were calculated each msec and displayed on a PC screen that also displayed the occurrence of each visual stimulus and the subject's response. Changes in the output of the IR detection system were linearly related to the calibrated amplitude of eye movements. Blinks, grimaces and saccades were distinguishable, as confirmed by video recordings of the subject's face. The A, PCV and D of each blink during a 3-min period in the middle of each 10-min JTV were measured from the PC screen using the same arbitrary units of distance for each.

Results:

The characteristics of a normal blink are shown in Fig 1 in terms of its amplitude (A), peak closing velocity (PCV) and duration. It is difficult to be sure when a blink ends and the eyelids are finally open. The duration of blinks is more accurately measured by their duration (D) at half their amplitude. The mean D for alert subjects here was 111 +/- 51 msec, and the normal range was 59-182 msec.

In all 12 subjects when alert, the A and PCV of blinks were highly correlated (Fig 2) ($r=0.82$, $n=202$, $p<0.001$), as expected.

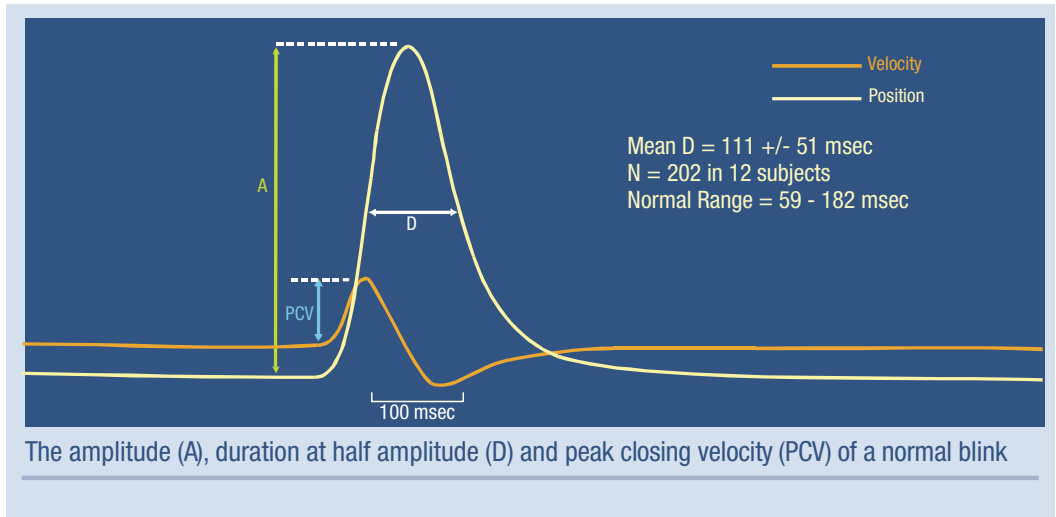


Fig. 1

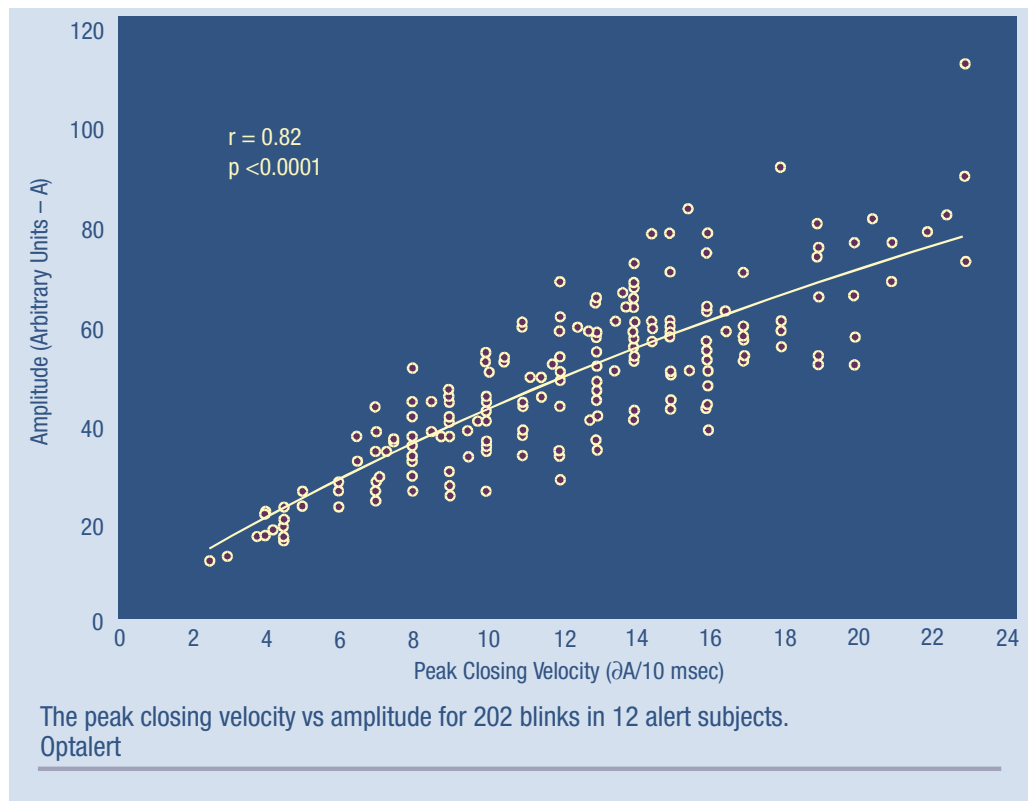


Fig. 2

The mean AVR for alert subjects was 4.1 +/- 0.8 (sd). This variable was normally distributed (Fig 3).

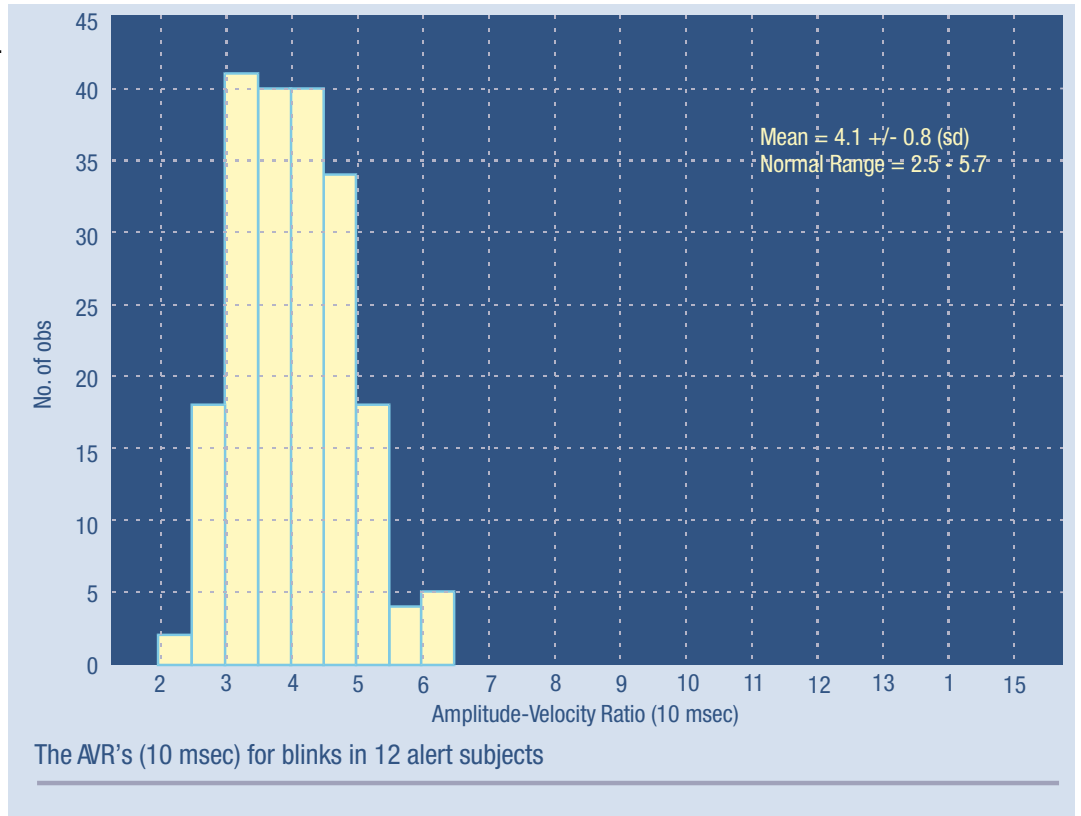


Fig. 3

In the drowsy state, the form of some blinks changed. Eyelid closing and opening was slower, and intermittently there were periods of prolonged eyelid closure (Fig 4). Partial blinks, in which the eyelids did not close fully, were common.

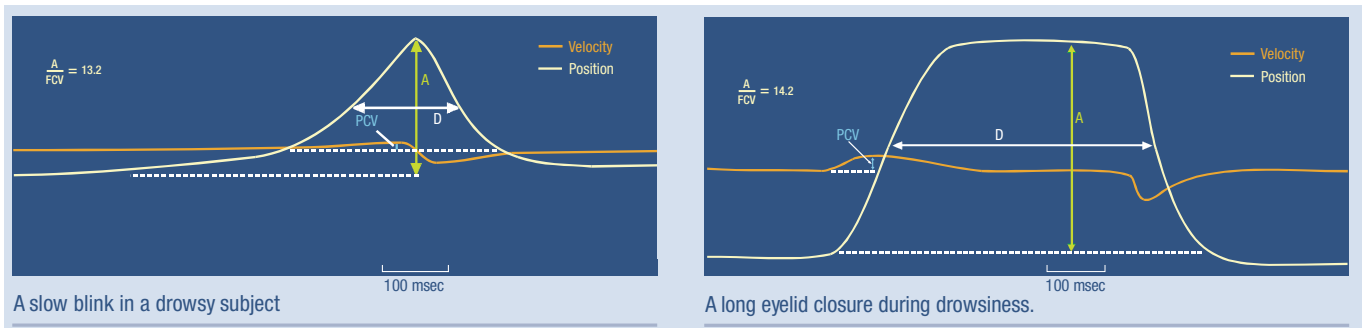


Fig. 4

The mean AVR in all 12 subjects increased after sleep deprivation to 6.4 +/- 6.0 (ANOVA, p<0.0001)(Fig 5). Many AVR's in drowsy subjects remained within the normal range (2.5-5.7). However higher AVR's appeared intermittently in all subjects with a frequency of at least 2/min, more in some subjects than others. The latter blinks had abnormally low velocity in relation to their amplitude. Some of these blinks were of abnormally long duration (D at _ amplitude >182 msec) but two thirds of them were of normal duration. Some were only partial blinks

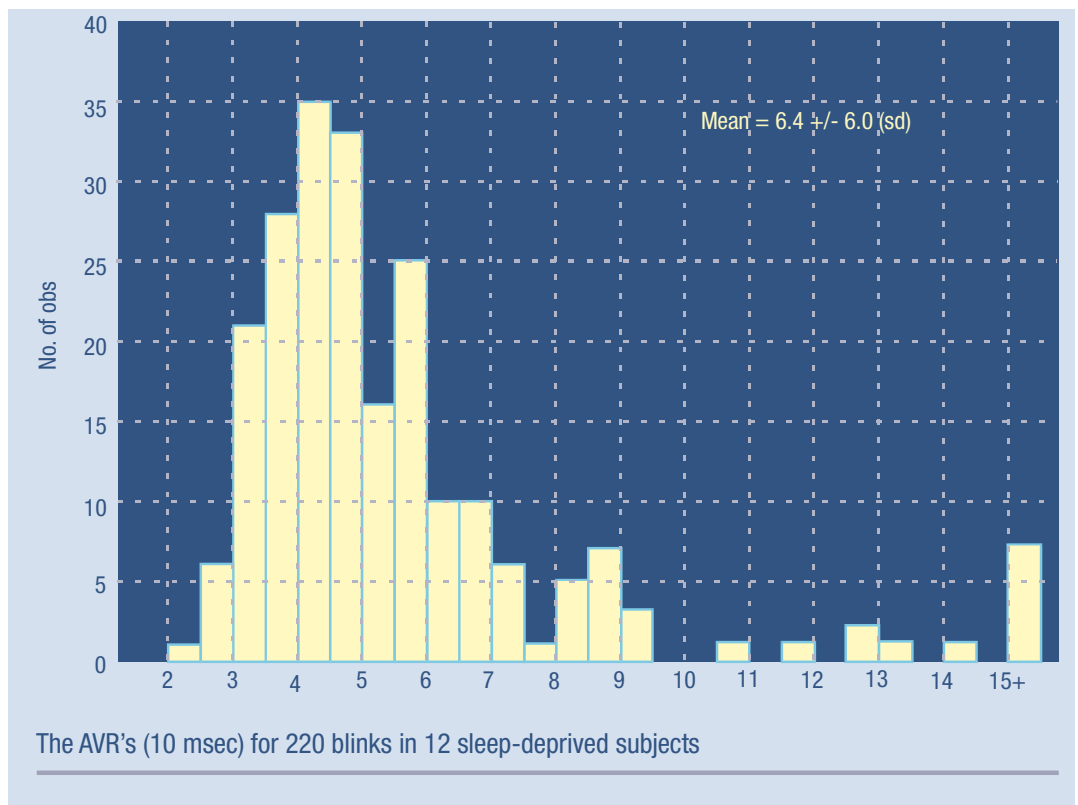


Fig. 5

Fig 6 shows the mean AVR's in one subject during performance tests done repeatedly during the night. There was no significant change in AVR's until after 2.30 am (ie. after about 19 hours of wakefulness), after which there was a progressive increase in AVR's.

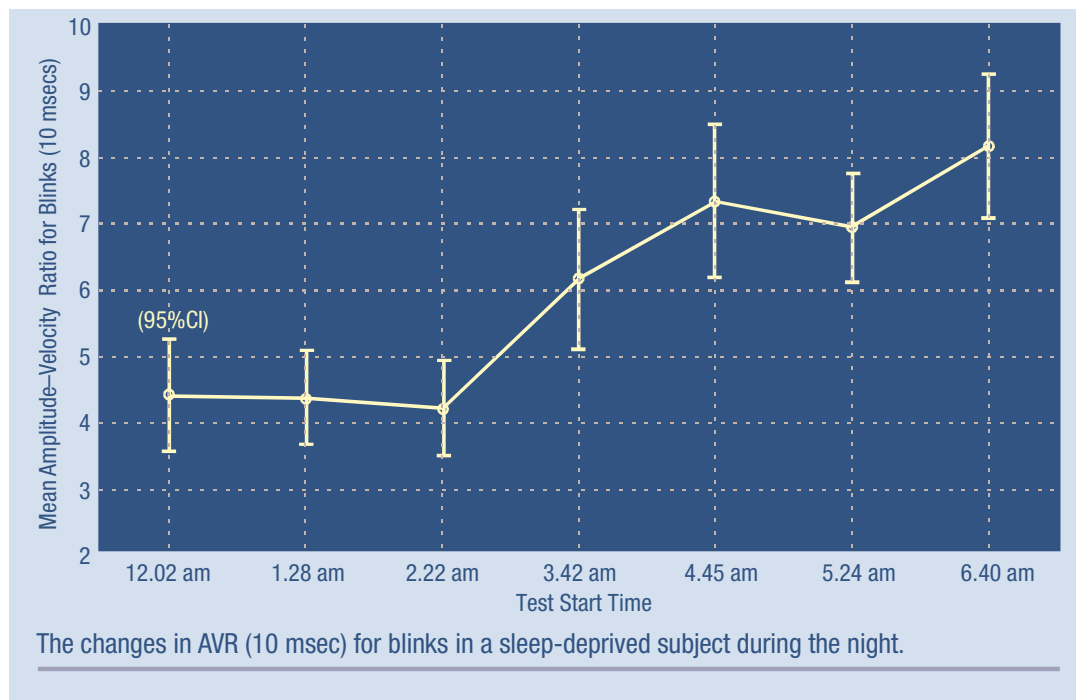


Fig. 6

Fig 7 shows the AVRB (in yellow) for each blink during one minute of the performance test in an alert subject. The subject's simple reaction times to the visual stimuli during that time are shown in green.

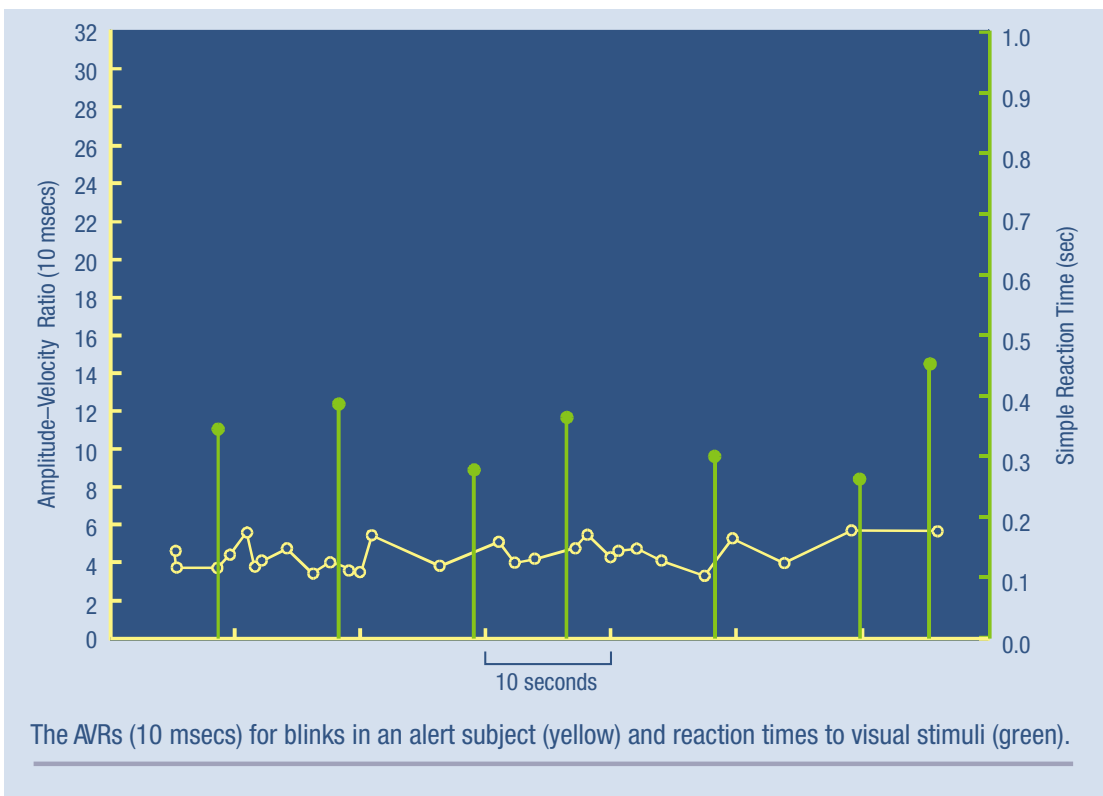


Fig. 7

Fig 8 shows the AVRBs and simple reaction times during a minute for the same subject as in Fig 7 when drowsy because of sleep deprivation. There were four periods, each lasting several seconds, when AVRBs were abnormal (>5.7). The subject responded to six of the seven stimuli during that minute, albeit with longer reaction times than when alert. However, when a stimulus coincided with a period of abnormal AVRBs, the subject did not respond at all (shown in orange). He was not aware of this.

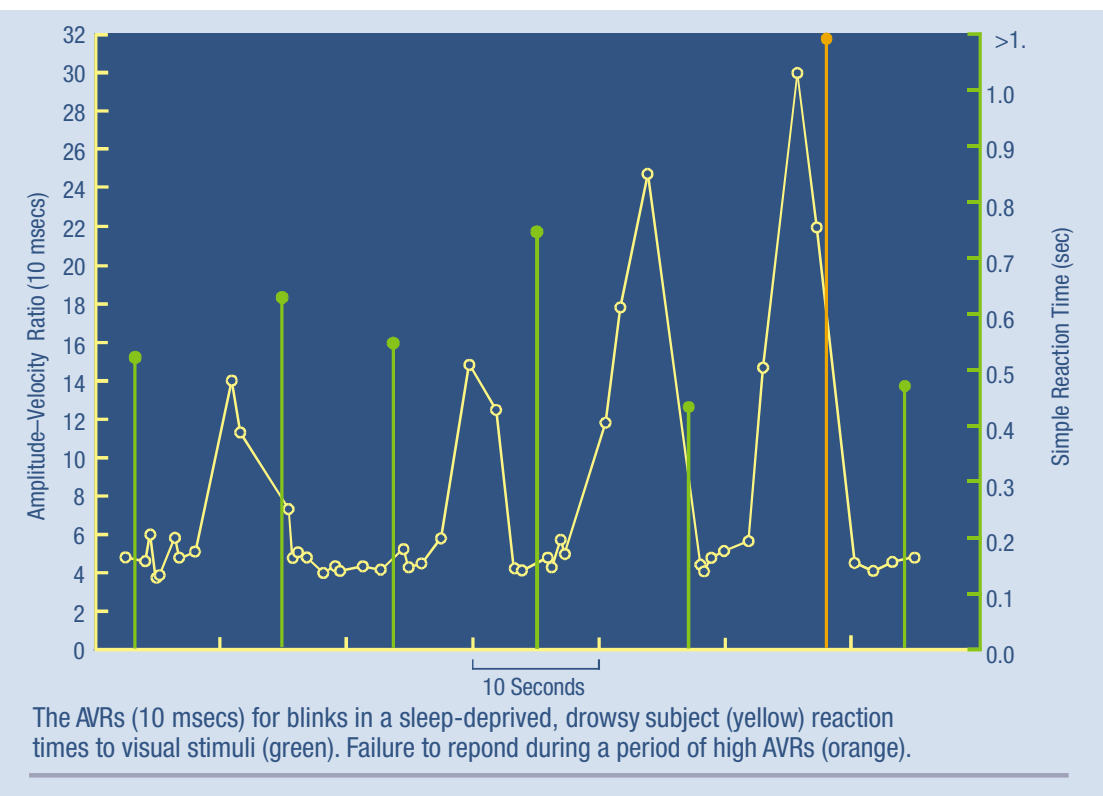


Fig. 8

The nine subjects who did JTVs, with and without sleep deprivation, were presented in those tests with a total of 3631 visual stimuli. They responded to all but 23 stimuli within one sec. Such lapses in performance (errors of omission) were seen in only four of the nine subjects, and only when they were sleep deprived. Fig 9 shows the mean AVRB for the latter four subjects when they were alert. It also shows that their AVRBs increased during the 60-30 sec before lapses in performance ($p < 0.001$), and increased further again during the 30-sec periods immediately before lapses ($p < 0.01$).

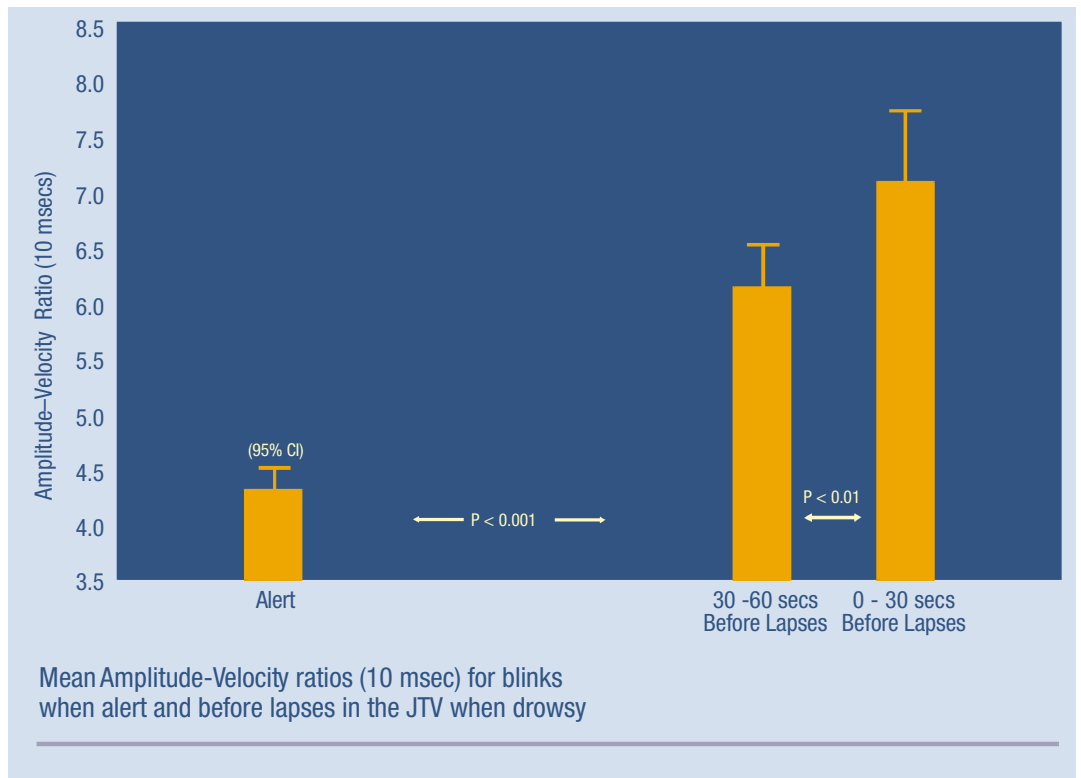


Fig. 9

Discussion:

The results indicate that the ratio of the amplitude (A) to the peak closing velocity (PCV) of blinks provides a useful new measure of drowsiness. Because this ratio (AVRB) has the dimension of time, not of distance or velocity, it can be measured from uncalibrated recordings.

AVRBs increased after about 19 hr of wakefulness, coinciding in time with about 2.30 am, as is also reported to occur with lapses in performance of a variety of tests. Increased AVRBs preceded lapses in performance. Some higher-than-normal AVRBs were directly associated with prolonged eyelid closure, but many were not.

In a companion poster (No 73) it is reported that the majority (78%) of lapses in performance recorded here occurred while the subject's eyes were open for at least long enough to see the stimulus under normal circumstances. The other lapses occurred while the eyelids were closed. Thus, drowsy lapses were not simply due to eyelid closure, but probably also involved central (neural) inhibition of vision. The latter lapses would not be detected by a video-camera method such as PERCLOS that relies on detection of prolonged eyelid closures.

A patent is pending for a new device based on AVRBs for monitoring drowsiness in people such as truck drivers, etc. This method (Optalert) can operate in sunlight or darkness, regardless of the position or movement of the subject's head, and does not involve the attachment of electrodes.

References:

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