



HAL
open science

Physiological Markers of Vigilance Variation in a Supervisory Task

Nicolas Maille, Mick Salomone, Andrea Desantis, Kevin Le Goff, Mauro Marchitto, Jean-François Sciabica, Marie-Christine Bressolle, Bruno Berberian

► **To cite this version:**

Nicolas Maille, Mick Salomone, Andrea Desantis, Kevin Le Goff, Mauro Marchitto, et al.. Physiological Markers of Vigilance Variation in a Supervisory Task. AHFE (Applied Human Factors and Ergonomics) 2022 International conference, Jul 2022, New York, United States. hal-03829580

HAL Id: hal-03829580

<https://hal.science/hal-03829580>

Submitted on 25 Oct 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1 Physiological Markers of Vigilance 2 Variation in a Supervisory Task

3 Nicolas Maille¹, Mick Salomone¹, Andrea Desantis¹,
4 Kevin Le Goff², Mauro Marchitto², Jean-François Sciabica²,
5 Marie-Christine Bressolle², and Bruno Berberian¹

6 ¹Information Processing and Systems Department, ONERA, Salon de Provence, 13660,
7 France

8 ²Human Factor Department, Airbus Operations, Toulouse, 31300, France

9 ABSTRACT

10 Many recent studies show that physiological markers can support the assessment of
11 cognitive states such as human attention or vigilance variation. In the perspective of
12 new cockpit or future products that are evaluated in a more ecological simulation con-
13 text, we investigate which and how such physiological metrics could complete the
14 often used classical methods such as subjective ratings or direct observation. Before
15 assessing their robustness in a more ecological environment, we present the results
16 of two experiments aiming to select the set of relevant metrics: A psychomotor vigila-
17 nce task classically used in the study of vigilance and a second task that combined an
18 alarm detection task and a supervisory task. Global results show that the combination
19 of ECG and eye-tracking indicators is a promising solution for the investigation of pilot
20 vigilance decrement in a cockpit simulator.

21 **Keywords:** Vigilance, Physiological markers, Supervisory task, PVT

22 INTRODUCTION

23 Vigilance or sustained attention refers to the ability of individuals to moni-
24 tor the situation in a continuous stream and detect infrequent or occasional
25 critical features over time. The ability to maintain an appropriate level of
26 vigilance over long periods of time underlies success on a range of tasks. Par-
27 ticularly, staying alert allows to detect infrequent signals and to allocate the
28 right level of cognitive resources to respond to expected or unexpected events.
29 In this context, valid assessment of vigilance is operationally important.

30 Vigilance is typically assessed using subjective, performance-based, and/or
31 physiological measures. Subjective ratings involve sampling the participant
32 response to the amount of vigilance used by using a questionnaire (Ross, Rus-
33 sell, & Helton, 2014). However, self-assessment techniques when performed
34 during the test should not be too frequent in order to limit their impact on
35 the task. Moreover, human beings are often inefficient when assessing their
36 own cognitive states. Performance measurement is based on the evaluation
37 of an individual's ability to perform the task. There is a long history of using
38 decreased performance with time on task as a gauge of vigilance decrement
39 (Warm, Matthews, & Finomore, 2008). Examples of performance metrics

40 susceptible to vigilance include reaction time, response speed to emergency
41 events, and lapses. However, such metrics are not always easy to implement
42 when it comes to supervisory tasks and the level of vigilance can someti-
43 mes vary without directly impacting the level of performance in the task. In
44 this context, there is a need for both unobtrusive and more sensitive meth-
45 ods for assessing operator vigilance. Physiological measurement of vigilance
46 has been proposed in this sense (Oken, Salinsky, & Elsas, 2006). Physiologi-
47 cal measures of vigilance are devoted primarily to continuous measurement
48 of the physical responses of the body. These changes are measured in car-
49 diac activity, brain activity, respiratory activity, and eye activity. Interestingly,
50 physiological metrics appear to be more sensitive (i.e., physiological meas-
51 ures may be able to detect a drop in alertness before operators can report it)
52 than subjective and performance based metrics. These findings are interesting
53 for human factors in aeronautics as it appears as a way to complement the
54 self-assessment ratings and observations with physiological metrics collected
55 during assessment with pilots in a cockpit simulator.

56 However, before integrating a set of physiological metrics in a representa-
57 tive cockpit, we propose to test the robustness of a selection of physiological
58 metrics proposed in two lab tasks: A psychomotor vigilance task (PVT) clas-
59 sically used in the study of vigilance and a second task that combined an
60 alarm detection task and a supervisory task. Particularly, we proposed to
61 explore four different markers of vigilance derived from electrocardiogra-
62 phic (heart rate variability), oculometric (blink frequency and eye closure)
63 and electroencephalographic (alpha power) signals. The objective is to assess
64 the robustness of the selected physiological markers selected.

65 **EXPERIMENTAL DESIGN**

66 **Participants**

67 Seventeen participants participated in the experiment. Eight participants (4
68 males; $M = 25$ y.o. $SD = 3.6$) completed the first task (PVT) while nine
69 participants (5 males; $M = 23.2$ y.o.; $SD = 4$) completed the second task
70 (supervisory task). All participants were voluntary and naive to the study's
71 hypotheses.

72 **Tasks**

73 *Psychomotor Vigilance task* – Psychomotor vigilance task (PVT) has emerged
74 as one of the most widely used tools to assess vigilant attention in fundamen-
75 tal (Chua et al., 2014) and applied research (Ferguson et al., 2008; Russo
76 et al., 2005). The PVT is a computer-based reaction-time task, pioneered by
77 Dinges and Powell (1985). It allows the collection of a large amount of data
78 in a relatively short period of time. These characteristics increase the sen-
79 sitivity of the test to detect even small changes in vigilant attention. In our
80 version of the PVT, each trial (Figure 1) started with the presentation of a
81 yellow rectangle on a black background. Participants attended to the LED
82 display for the duration of the test (30 min) and were instructed to press a
83 central button as quickly as possible after the appearance of a visual stimulus

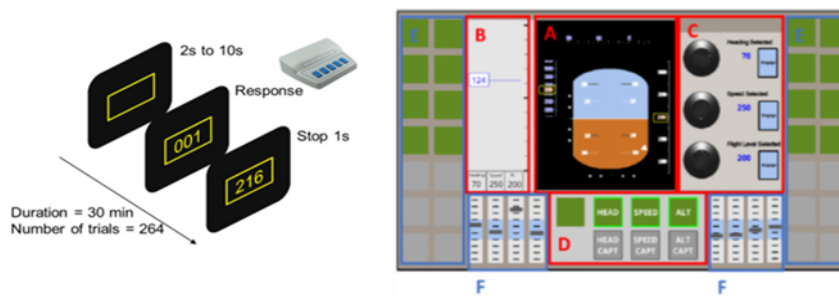


Figure 1: Procedure for a trial of the psychomotor vigilance task (left) and autopilot interface used for SAMT (right).

84 (a timer) presented at a variable interval of 2–10 sec. The displayed value,
 85 corresponding to the participants' RT, remained displayed for 1s. Given the
 86 simplicity of the task, the participants performed three trials beforehand to
 87 practice.

88 *Simplified Aircraft Monitoring Task (SAMT)* – In this study, we propose
 89 a set of tasks representative of those performed in aircraft piloting. Derived
 90 from the multi-attribute task battery (MATB) classically used in aeronautics,
 91 we focus here on the supervisory components of the pilot task. In this
 92 sense, we designed a new task called SAMT. In this task, participants inter-
 93 acted with a tactile interface (Figure 1). They had to perform two subtasks
 94 in parallel: supervise the actions of the autopilot and detect alarms. The first
 95 subtask required to control the heading, speed, and altitude of the aircraft
 96 using the autopilot interface. For this task, displays A, B, C and D were used.
 97 Display A indicates the altitude, the speed and the course followed but also
 98 the orientation of the aircraft compared to the horizon. Display B indicates
 99 the instructions to follow. In addition to presenting the values to be follo-
 100 wed, above each parameter were scrolled the next values to be adopted and
 101 the timing to follow. Participants had to set the values to be tracked via screen
 102 C. Finally, screen D allowed the participants to know if the parameters were
 103 followed by the autopilot. The second subtask was performed via screens E
 104 and F. For the squares appearing on screen E, the participants had to press
 105 as quickly as possible on the square whose color had changed. The gauges in
 106 the F screens oscillated vertically and had to stay in the blue zone. If a gauge
 107 moved out of this boundary, participants had to press that gauge as quickly
 108 as possible as well. This detection task took priority over the supervision
 109 task. A total of 16 alarms appeared during the task. The appearance of these
 110 16 alarms was divided into 4 separate blocks according to their appearance
 111 frequency (i.e. high or low). When the frequency was low, the block lasted
 112 16 minutes, whereas when it was high, the block lasted 8 minutes. The task
 113 was composed of two blocks of each frequency. They appeared in alternation
 114 (low, high, low high).

115 Measures

116 As mentioned above, we were interested in four different markers of vigilance
 117 derived from electrocardiographic, oculometric and electroencephalographic
 118 signals.

119 *Electrocardiographic markers* – ECG data were recorded using Biopac
120 system. The evolution of heart rate variability (HRV), that is how much
121 the heart rate varies, has been computed for the two tasks performed. First
122 empirical evidence indicated that decrease in vigilance is characterized by an
123 increase in HRV (Porges & Raskin, 1969). Nowadays, the heart rate varia-
124 bility (HRV) is used as a robust metrics for vigilance measurement (Larue,
125 Rakotonirainy, & Pettitt, 2011; Henelius, et al., 2014). In our study, we used
126 a time-domain indicator called SDNN. SDNN is calculated as the standard
127 deviation of all of the RR intervals (i.e., the distance between each heartbeat)
128 and was computed for the 2min time windows.

129 *Oculometrics markers* – Oculometric data were recorded using the hardw-
130 are SmartEye Pro 3.0 and the software SmartEye 6.2.4. The system included
131 2 infrared illuminators and 3 cameras (120 Hz) placed above the screen to
132 avoid any direct contact with the participant. Two different metrics were
133 collected: the PERcentage of eyelid CLOSure (or PERCLOS) and the blink
134 frequency. PERCLOS measures the percentage of time during which the
135 eyes are closed over a window of several minutes (usually 1 to 3 minu-
136 tes). An eye closure is usually characterized by an 80% (sometimes 70%)
137 closure of the eye compared to its nominal size. The correlation between
138 PERCLOS and performance decrements in vigilance tasks has been demon-
139 strated in a number of experiments (Wierwille, et al., 1994; Dinges, Mallis,
140 Maislin, & Powell, 1998). Blink frequency is a well-validated indicator of
141 visual attention; it is reduced during periods when attention is oriented tow-
142 ard significant external stimuli, and this reduction is proportional to the
143 required attention (Campagne, Pebayle, & Muzet, 2005; Stern, Walrath, &
144 Goldstein, 1984). It corresponds to the number of blinks over a given time
145 window. Note that we used the blinks identified by the Smart Eye algorithm in
146 our study.

147 *Electroencephalographic metrics* – EEG data were recorded using acti-
148 CHamp system. In our study, we were interested in the evolution of the
149 alpha power. Nowadays, there is a very large literature concerning the rela-
150 tionship of oscillatory activity and vigilance (Fuxe, & Snyder, 2011; Frey,
151 Ruhnau, & Weisz, 2015). Overall, there is increased slow frequency activity
152 (alpha and theta bands) with decreasing vigilance. After signal preprocessing
153 (segmentation, 2nd order Butterworth bandpass filter from 1Hz to 80 Hz
154 and a notch for 49 to 51Hz, visual inspection and signal rejection, ICA), we
155 performed a time-frequency analysis of the time series by applying a Mor-
156 let transform to each segment. For the PVT data analysis, the trials were
157 separated into 4 blocks and the 1st block was used as the baseline. For
158 the supervision task, the rest period was chosen as the baseline. Normali-
159 zation was performed by dividing the spectral power by that of the baseline
160 and the measurements were then expressed in decibel via a logarithmic tran-
161 sformation. In both cases, the alpha frequency band was between 8Hz and
162 14Hz. In the PVT, the analysis was restricted to the electrodes located on
163 the occipital lobe (i.e. O1, O2 and Oz) whereas in the correlation analyses
164 performed with the supervisory task data, all the electrodes were taken into
165 account.

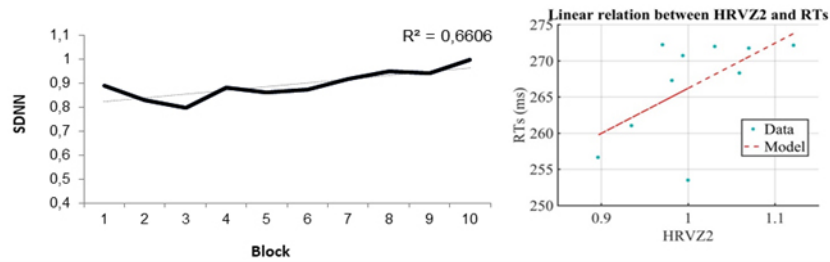


Figure 2: Time course of HRV (left) and RT/HRV relationship (right) during the psychomotor vigilance task.

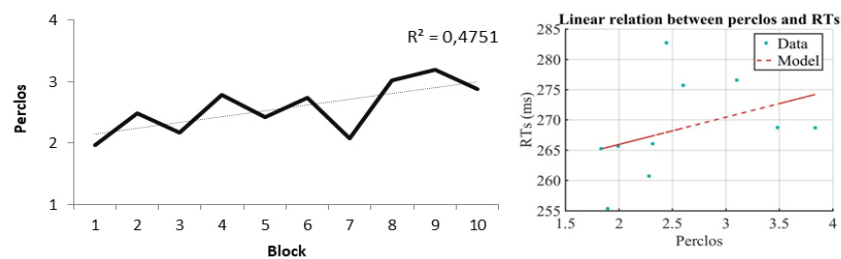


Figure 3: Time course of PERCLOS (left) and RT/PERCLOS relationship (right) during the psychomotor vigilance task.

166 RESULTS

167 PVT Results

168 As a reminder, performance metrics are typically used as vigilance markers
 169 during this PVT task, so trials characterized by low vigilance generate higher
 170 reaction times. In this context, we were interested in 1/ the evolution of our
 171 physiological markers over time, 2/ the relationship between these markers
 172 and reaction times.

173 Before exploring the evolution of our physiological metrics, we explored
 174 the evolution of reaction times over time to assess whether a decrease in per-
 175 formance was observed during the task. At the behavioral level, we did not
 176 observe a significant decrease in performance over time $F(1,14) = 1.5, p > 0.1$.

177 *ECG* - The results (Figure 2) show a linear relationship between the time
 178 on task and HRV ($R^2=0.6606$). Furthermore, when we look at the correla-
 179 tion between this metric and RTs, we find that when we add the HRV factor
 180 to our RT explanation model, it predicts Reaction Times (RTs) better than a
 181 simple model where we only take the average of RTs ($p = 0.001772$).

182 *Oculometric measure* - The results (Figure 3) show a linear relationship
 183 between the time on task and PERCLOS ($R^2=0.4751$). As observed for
 184 HRV, there also appears to be a relationship between RT and PERCLOS such
 185 that a model with PERCLOS predicts the obtained RT better than without
 186 ($p = 0.005364$). Contrary to the results obtained for PERCLOS, no relation-
 187 ship between blink frequency and time is observed. Furthermore, the addition
 188 of the “Blink frequency” indicator does not explain predict the RT data better
 189 than without.

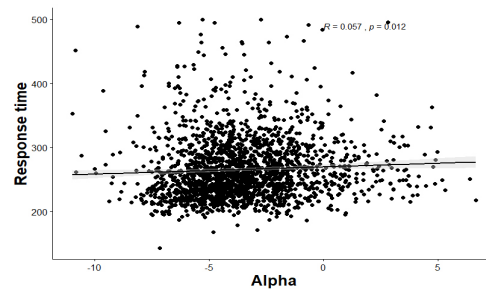


Figure 4: RT/Alpha Power relationship during the PVT.

190 *EEG measure* - In contrast to the other metrics, we do not observe a change
 191 over time in alpha activity. However, analysis of the correlation between
 192 response time and alpha activity associated with each trial demonstrates a
 193 positive correlation between alpha and RTs ($r = 0.068$, $p = 0.0016$), so that
 194 the higher the reaction time (and therefore the lower the performance), the
 195 the higher the alpha (Figure 4).

196 The results obtained during the PVT seem to confirm the relevance of the
 197 proposed metrics (HRV, PERCLOS and Alpha Rhythm) as markers of the
 198 evolution of vigilance, contrary to the results obtained for blink frequency. In
 199 particular, these three metrics are correlated with performance in this psych-
 200 omotor vigilance task. In a second step, we were interested in the evolution of
 201 the three “responsive” metrics (i.e., HRV, PERCLOS & alpha activity) during
 202 our supervisory task (i.e., the SAMT).

203 **SAMT Results**

204 In this second experiment, we were interested in the decrease in vigilance over
 205 time and compare different periods with low and high alarm frequency. The
 206 question was therefore whether the three successful physiological measures in
 207 our first experiment were sensitive to the phenomenon of vigilance decrement
 208 in a supervisory task.

209 *ECG* - The results demonstrate an increase in HRV over time (Figure 5),
 210 as previously observed in the PVT task ($R^2=0.8833$). As a reminder, the dif-
 211 ficulty of the detection task evolved during the 4 blocks (low, high, low, high)
 212 which explains the evolution observed (increase between block 1 and 2, then
 213 decrease between block 2 and 3, then increase “again between block 3 and 4).

214 *Oculometric measure* - A same tendency is observed for the PERCLOS
 215 (Figure 5), with an increase in PERCLOS over time ($R^2=0.6149$).

216 *EEG measure* - Finally, we observed a marginal increase in alpha over time
 217 (-4.8 vs -4.2 Hz), $F(1,8) = 4.4$, $p < 0.1$.

218 The three metrics that were responsive to changes in vigilance during the
 219 PVT task are therefore found to be also responsive to changes in vigilance
 220 during our SAMT task. In addition, we also added a subjective scale (Samn-
 221 Perelli) before and after completion of the supervisory task to explore changes
 222 in fatigue levels. Participants report an increase in fatigue (Samn-Perelli) after
 223 the supervision task (4 vs. 4.8), $F(1,8)= 5.8$, $p < .05$.

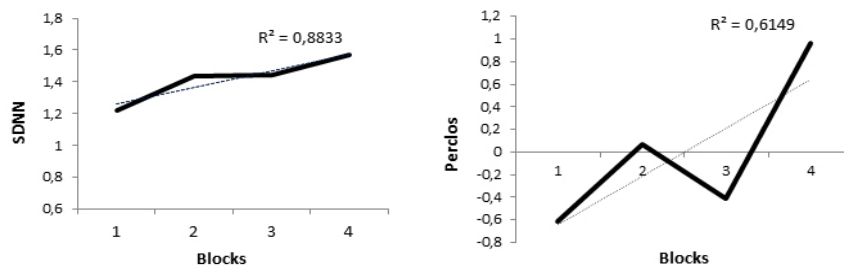


Figure 5: Time course of HRV (left) and PERCLOS (right) during the supervisory task.

224 CONCLUSION

225 In this study, we proposed to assess the interest of the four physiological
 226 markers: heart rate variability, blink frequency, eye closure and EEG alpha
 227 power. To do so, we used two different tasks: a task classically used in the
 228 study of vigilance (i.e., the psychomotor vigilance task or PVT) and a task of
 229 monitoring an automatic pilot. The first study allowed us to demonstrate that
 230 the PERCLOS, the heart rate variability and the EEG alpha power were sensi-
 231 tive to variations in vigilance. In particular, we observed that these metrics
 232 were significantly correlated with changes in reaction times, a metric classi-
 233 cally used in the PVT task as a marker of vigilance state. Interestingly, we also
 234 observed that these physiological metrics seem to be sensitive to the decrease
 235 of vigilance over time classically put forward in these vigilance tasks, where
 236 the only behavioral metrics classically used in PVT task (here, RT) would not
 237 allow to highlight a significant loss of vigilance. The relevance of these physi-
 238 ological markers to highlight decreases in vigilance over time is confirmed in
 239 the SAMT since the three metrics previously highlighted show a sensitivity to
 240 time on task consistent with the evolution of the level of fatigue reported by
 241 the participants. Thus, it appears that the sensitivity of these metrics to chan-
 242 ges in vigilance does not depend on the nature of the task. The use of SAMT
 243 also allowed us to explore this decrease in alertness in an underload context,
 244 which allows us to get closer to the ecological context. Taken together, these
 245 results confirm the relevance of physiological measures to characterize and
 246 quantify changes in vigilance levels over time. The next step will be to evalu-
 247 ate the robustness of these metrics in a representative cockpit. One limitation
 248 concerns the difficulty of relating performance to decreased vigilance in our
 249 SAMT. One prospect would be to identify performance metrics that might be
 250 relevant for use in this task.

251 REFERENCES

- 252 Campagne, A., Pebayle, T., & Muzet, A. (2005) Oculomotor changes due to
 253 roads incidents during a prolonged monotonous simulated driving. *Biological*
 254 *Psychology*, 68, 353–368.
 255 Chua, E.C.P., Yeo, S.C., Lee, I.T.G., Tan, L.C., Lau, P., Cai, S., ... & Gooley, J.J.
 256 (2014). Sustained attention performance during sleep deprivation associates with
 257 instability in behavior and physiologic measures at baseline. *Sleep*, 37(1), 27–39.

- 258 Dinges, D.F., Mallis, M.M., Maislin, G., & Powell, I.V. (1998) Evaluation of tech-
259 niques for ocular measurement of an index of fatigue and the basis for alertness
260 management. NHTSA report DOT HS, 808, 762.
- 261 Dinges, D.F., & Powell, J.W. (1985) Microcomputer analyses of performance on a
262 portable, simple visual RT task during sustained operations. *Behavior Research*
263 *Methods*, 17, 652–655.
- 264 Foxe, J.J., & Snyder, A.C. (2011) The role of alpha-band brain oscillations as a sen-
265 sory suppression mechanism during selective attention. *Frontiers in psychology*,
266 2, 154.
- 267 Ferguson, S.A., Lamond, N., Kandelaars, K., Jay, S.M., & Dawson, D. (2008). The
268 impact of short, irregular sleep opportunities at sea on the alertness of marine
269 pilots working extended hours. *Chronobiology international*, 25(2-3), 399–411.
- 270 Frey, J.N., Ruhnau, P., & Weisz, N. (2015). Not so different after all: The same
271 oscillatory processes support different types of attention. *Brain research*, 1626,
272 183–197.
- 273 Henelius, A., Sallinen, M., Huutilainen, M., Müller, K., Virkkala, J., & Puolamäki,
274 K. (2014) Heart rate variability for evaluating vigilant attention in partial chronic
275 sleep restriction. *Sleep*, 37(7), 1257.
- 276 Larue, G.S., Rakotonirainy, A., & Pettitt, A.N. (2011) Driving performance
277 impairments due to hypovigilance on monotonous roads. *Accident Analysis &*
278 *Prevention*, 43(6), 2037–2046.
- 279 Oken, B.S., Salinsky, M.C., Elsas, S. (2006) Vigilance, alertness, or sustained atten-
280 tion: physiological basis and measurement. *Clinical neurophysiology*, 117(9),
281 1885–1901.
- 282 Porges, S.W., Raskin, D.C. (1969) “Respiratory and heart rate components of
283 attention.” *Journal of experimental psychology* 81(3), 497.
- 284 Ross, H.A., Russell, P.N., Helton, W.S. (2014) Effects of breaks and goal switches on
285 the vigilance decrement. *Experimental brain research*, 232(6), 1729–1737.
- 286 Russo, M.B., Kendall, A.P., Johnson, D.E., Sing, H.C., Thorne, D.R., Escolas, S.M.,
287 ... & Redmond, D.P. (2005). Visual perception, psychomotor performance, and
288 complex motor performance during an overnight air refueling simulated flight.
289 *Aviation, space, and environmental medicine*, 76(7), C92–C103.
- 290 Stern, J.A., Walrath, L.C., & Goldstein, R. (1984) The endogenous eyeblink.
291 *Psychophysiology*, 21(1), 22–33.
- 292 Warm, J.S., Matthews, G., Finomore, V.S. (2008) Workload, stress, and vigilance.
293 In P. A. Hancock & J. L. Szalma (Eds.), *Performance under stress* (pp. 115–141).
294 Brookfield, VT: Ashgate.
- 295 Wierwille, W.W., et al. (1994) Research on vehicle-based driver status/performance
296 monitoring; development, validation, and refinement of algorithms for detection
297 of driver drowsiness. final report. No. HS-808 247.