Age, performance and sleep deprivation

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Accepted in revised form 14 April 2004; received 28 October 2003

SUMMARY Young subjects are frequently involved in sleep-related accidents. They could be more affected than older drivers by sleep loss and therefore worsen their driving skills quicker, or have a different perception of their level of impairment. To test these hypotheses we studied variations of reaction time (RT), a fundamental prerequisite for safe performing, as measured by lapses, i.e. responses $\geq$500 ms and self-assessment of performance and sleepiness after a night awake and after a night asleep in a balanced crossover design in young versus older healthy subjects. Ten young (20–25 years old) and 10 older volunteers (52–63 years old) were tested with and without 24 h of sleep deprivation. Without sleep deprivation, RTs were slower in older subjects than in the younger ones. However, after sleep deprivation, the RTs of young subjects increased while that of the older subjects remained almost unaffected. Sleepiness and self-perception of performance were equally affected in both age groups showing different perception of performance in the age groups. Our findings are discussed in terms of vulnerability to sleep-related accidents.

KEYWORDS age, simple reaction time, sleepiness, sleep deprivation, sleep-related accidents

INTRODUCTION

Sleep deprivation is known to impair cognitive functions (Dinges et al., 1997; Jewett et al., 1999; Van Dongen et al., 2003). Of the many tests of cognitive function, reaction time (RT) testing is a highly sensitive measure of sustained attention, which is a fundamental prerequisite for safe performing (Philip et al., 2003).

Age is also known to affect RT. Older subjects perform significantly slower than young subjects (Wilkinson and Allison, 1989) in normal conditions. This difference between young and old does not seem so clear under conditions of sleep deprivation.

Carskadon and Dement (1985) initially found that old subjects (61–77 years old) responded to sleep deprivation in a similar way to younger subjects, but other studies using partial sleep deprivation (Bonnet, 1989) or total sleep deprivation (Bonnet and Arand, 1989) showed a possibly higher resistance to sleep deprivation in older subjects than in the younger ones. These differences were clearly noted between young and old (Smulders et al., 1997) or very old subjects (Brendel et al., 1990).

Webb (1981) using a different protocol compared the recovery of young (18–22 years) and older subjects (40–50 years) after two nights of sleep loss. He found that younger subjects tended to enter slow wave sleep more quickly possibly suggesting a higher sleep need. In two other studies he also found that older subjects were more vulnerable than younger with respect to performance decrement during sleep deprivation (Webb, 1985; Webb and Levy, 1982).

Because young subjects are frequently involved in sleep-related accidents (Connor et al., 2001, 2002; Horne and Reyner, 1995) one could speculate that young drivers are more affected than older drivers by sleep loss and therefore worsen their driving skills more quickly. Another explanation for this age effect could be a difference in the perception of the level of impairment in dangerous conditions (i.e. sleep deprivation).

In a previous study (Philip et al., 1999), we compared the performances on a simple RT test of young (<30 years old)
and older drivers (≥30 years old) during rest stops on a freeway area. We showed that age plays a major role in tolerance to driving-related fatigue. Young drivers have better performances than older drivers after a short trip (2–4 h), but they suffer much more from performance decrement than older drivers after 8 h of driving, showing a high vulnerability to fatigue.

In order to confirm our previous results and to test the hypothesis of a greater vulnerability of younger subjects, we designed a protocol evaluating the potential protective role of age on the consequences of sleep deprivation using RT (median and lapses) and self-perception of fatigue, sleepiness and performance as cognitive markers.

METHODS

Subjects

Ten healthy young male subjects (mean age 22.5 ± 2.2 years; range 20–25 years) and 10 healthy older male subjects (mean age 58.2 ± 4.1 years; range 52–63 years) were recruited. All the subjects provided written informed consent, and the study was approved by the local ethics committee.

Inclusion criteria

Subjects underwent a clinical evaluation, an interview with a sleep specialist and one nocturnal polygraphy to eliminate subjects with sleep disorders. We used actimetry recordings (Shinkoda et al., 1998) to quantify the sleep duration and to eliminate any subject with sleep–wake schedule disorders. Each individual had 7 days of actimetry prior to inclusion. All subjects presenting a sleep efficiency inferior to 85% were excluded from the study. The selected participants were instructed to maintain a regular sleep–wake schedule (controlled by actimetry) for 3 days before the study periods. No stimulant use of any kind was allowed during the study.

Protocol

Subjects were tested in two different conditions in the laboratory: after controlled normal sleep (rested), and after a full night of sleep deprivation. One half of the subjects, chosen at random, started the experiment with the rested condition, and the other half started with the sleep-deprived condition. A minimum of 1 week was allowed between each testing period.

For the tests in the rested condition, subjects were monitored in the laboratory from 21:00 to 08:30 hours and were in bed from 23:00 to 07:30 hours. For the tests in the sleep-deprived condition, subjects were monitored in the laboratory from 21:00 to 08:30 hours, and prevented from sleeping. In both conditions, tests started at 9:00 hours.

Sleep and wake duration were monitored by actimetry during the two conditions (Actiwatch and Actiwatch sleep analysis software; Cambridge Neurotechnology, Cambridge, UK).

Subjects were tested every 2 h (9, 11, 13, 15, 17, 19 hours). Subjects were asked, "How well do you think you are going to perform on the RT test?". They rated their subjective assessment of future performance on a 100 mm visual analogue scale (VAS) from ‘excellent’ to ‘very poor’. In addition, subjects had to rate their instantaneous fatigue (describe how fatigued you are now) on a 100 mm VAS and sleepiness on the Karolinska sleepiness scale (KSS) (Akerstedt and Gillberg, 1990). Then they performed a 10-min simple RT test on a PALM personal organizer (Gillberg et al., 1994; Philip et al., 1999). After a 1-min training period, a black square was displayed 130 times on the screen at randomized (2–7 s) intervals, over 10 min. The subject's task was to respond to the stimuli by pressing a key to turn the square off. If no response was given within 1 s, a new interval was started. Pressing the key before the square was displayed, or within 100 ms, caused the response to be discarded and a warning to be displayed.

The software that controls the internal clock yields data with at least 0.01 ms resolution. (The keyboard is sampled at CPU frequency divided by the number of instructions needed for sampling.) Another part of the program calculates the number of responses above 500 ms (lapses; Dinges et al., 1997) during the 10 min task. Number of lapses was used as the dependent variable of our study. This sensitive technique allows to measure small variations of response rates such as noted during the increased instability of sleep–wake status found during sleep deprivation in humans (Doran et al., 2001). More than means, these slowest RTs are characteristic of episodes of sleepiness. The mean RT and the fastest RTs are more influenced by age than by sleepiness.

Statistical analysis

Actimeter results (sleep duration and sleep efficiency), fatigue and sleepiness scores are presented as mean and standard deviations.

The effect of the condition (rested versus sleep deprived) and time of testing on fatigue, sleepiness and performance (KSS) were evaluated by repeated measures analysis of variance (ANOVA). To correct for sphericity, all $P$ values derived from ANOVA were based on Huynh–Feldt’s corrected degrees of freedom.

In addition, performance results were analyzed using negative binomial regression in Stata 8 (Stata Corporation, College Station, TX, USA), using number of lapses per session per subject as dependent variable and category (older versus young), sleep condition (rested versus sleep deprived) and session number as determinants, clustered on subjects. The relative risk of performance impairment during sleep deprivation is expressed in reference to the first test of the day. In addition, the same negative binomial regression model was repeated within both categories (young and old).

Results are given as total number of lapses per session for all subjects and overall per sleep condition. Comparisons between
conditions and sessions are given as incidence rate ratios (IRR) with their 95% confidence intervals.

Self-perception of performances between conditions was compared using Student’s *t*-tests.

Correlations between performances and perception of fatigue and sleepiness were tested by a Spearman rank test.

**RESULTS**

**Actimetry**

During the rested sleep night, actimetric recordings indicated an estimated mean total sleep time of 477 ± 37 min for the young subjects and an estimated mean total sleep time of 498 ± 10 min for the older subjects. Sleep efficiency for the rested sleep night was 85.6 ± 8.4% for the young subjects and 91.5 ± 5.7% for the older subjects.

**Fatigue scale**

Mean values and standard deviations are presented in Table 1. A three-factor repeated measures ANOVA with category, condition and session as main explaining factors showed a significant effect for sleep deprivation (*F* = 49.2, *P* < 0.0005) and time of testing (*F* = 8.3, *P* < 0.0005). An interaction between time of testing and category (young versus older subjects) was also observed (*F* = 3.5, *P* = 0.008). Whereas the perception of fatigue in young subjects did not increase significantly over time, it did in older subjects in both conditions.

**Karolinska sleepiness scale**

Mean values and standard deviations are presented in Table 1. A three-factor repeated measures ANOVA with category (young versus older subjects), condition (rested versus sleep deprived) and session (time of testing) as main explaining factors showed a significant effect for sleep deprivation (*F* = 60.9, *P* < 0.0005) and time of testing (*F* = 4.3, *P* = 0.007).

**Reaction time**

Median RT

ANOVA. Median values and standard errors are presented in Table 2. We transformed median RT in z-scores to obtain a normal distribution. A three-factor repeated measures ANOVA with category (young versus older subjects), condition and session as main explaining factors showed a significant effect for sleep deprivation (*F* = 9.0, *P* = 0.008) and time of testing (*F* = 2.5, *P* = 0.04). Interactions between time of testing and category (*F* = 3.9, *P* = 0.004) and between condition and category (*F* = 4.3, *P* = 0.051) were observed.

<p>| Table 1 Mean self-rated fatigue scores (±SD) and mean self-rated sleepiness (KSS: Karolinska sleepiness scale) scores (±SD) for each point of measurement in the rested and sleep deprived (SD) conditions |</p>
<table>
<thead>
<tr>
<th>Time condition</th>
<th>9:00</th>
<th>11:00</th>
<th>13:00</th>
<th>15:00</th>
<th>17:00</th>
<th>19:00 hours</th>
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<tbody>
<tr>
<td><strong>Young subjects</strong></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>KSS in rested condition</td>
<td>2.7 ± 0.8</td>
<td>2.6 ± 1.0</td>
<td>3.1 ± 1.7</td>
<td>2.7 ± 1.0</td>
<td>3.1 ± 1.3</td>
<td>2.8 ± 1.0</td>
</tr>
<tr>
<td>KSS in SD condition</td>
<td>4.5 ± 2.7</td>
<td>5.6 ± 2.3</td>
<td>5.4 ± 2.3</td>
<td>4.9 ± 2.1</td>
<td>5.3 ± 2.5</td>
<td>5.7 ± 2.1</td>
</tr>
<tr>
<td>Fatigue in rested condition</td>
<td>26.5 ± 14.0</td>
<td>30.1 ± 18.3</td>
<td>28.1 ± 13.4</td>
<td>32.4 ± 20.3</td>
<td>32.2 ± 16.3</td>
<td>29.7 ± 17.5</td>
</tr>
<tr>
<td>Fatigue in SD condition</td>
<td>60.5 ± 25.0</td>
<td>65.8 ± 20.9</td>
<td>60.3 ± 20.6</td>
<td>64.1 ± 17.3</td>
<td>65.6 ± 25.6</td>
<td>65.6 ± 22.4</td>
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<tr>
<td><strong>Old subjects</strong></td>
<td></td>
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<tr>
<td>KSS in rested condition</td>
<td>1.9 ± 1.0</td>
<td>2.0 ± 0.9</td>
<td>2.2 ± 0.9</td>
<td>2.7 ± 1.2</td>
<td>3.1 ± 1.6</td>
<td>3.3 ± 1.7</td>
</tr>
<tr>
<td>KSS in SD condition</td>
<td>3.6 ± 2.0</td>
<td>4.8 ± 1.8</td>
<td>4.3 ± 1.8</td>
<td>5.7 ± 1.8</td>
<td>5.7 ± 1.6</td>
<td>5.2 ± 2.3</td>
</tr>
<tr>
<td>Fatigue in rested condition</td>
<td>20.6 ± 18.7</td>
<td>21.4 ± 14.6</td>
<td>27.9 ± 15.1</td>
<td>28.7 ± 11.7</td>
<td>32.2 ± 13.8</td>
<td>37.7 ± 21.2</td>
</tr>
<tr>
<td>Fatigue in SD condition</td>
<td>34.1 ± 12.2</td>
<td>46.8 ± 13.8</td>
<td>46.8 ± 10.9</td>
<td>57.0 ± 14.9</td>
<td>54.0 ± 11.7</td>
<td>57.0 ± 14.3</td>
</tr>
</tbody>
</table>

<p>| Table 2 Median of median RT (±SE) and lapses (±SE) for each point of measurement in the rested and sleep deprived (SD) conditions |</p>
<table>
<thead>
<tr>
<th>Time condition</th>
<th>9:00</th>
<th>11:00</th>
<th>13:00</th>
<th>15:00</th>
<th>17:00</th>
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<tbody>
<tr>
<td><strong>Young subjects</strong></td>
<td></td>
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<tr>
<td>Median RT in rested condition</td>
<td>266.5 ± 11.16</td>
<td>254 ± 16.79</td>
<td>246 ± 14.38</td>
<td>257 ± 11.34</td>
<td>267 ± 13.11</td>
<td>259.5 ± 16.34</td>
</tr>
<tr>
<td>Median RT in SD condition</td>
<td>279 ± 23.57</td>
<td>271 ± 29.47</td>
<td>259 ± 22.71</td>
<td>277.5 ± 48.27</td>
<td>266 ± 28.01</td>
<td>274.5 ± 19.67</td>
</tr>
<tr>
<td>Lapses in rested condition</td>
<td>1 ± 1.28</td>
<td>1 ± 1.55</td>
<td>1 ± 1.78</td>
<td>2 ± 0.96</td>
<td>1.5 ± 1.53</td>
<td>1 ± 2.18</td>
</tr>
<tr>
<td>Lapses in SD condition</td>
<td>7 ± 3.9</td>
<td>2 ± 4.92</td>
<td>3 ± 4.01</td>
<td>5.5 ± 5.79</td>
<td>4 ± 5.41</td>
<td>3.5 ± 2.82</td>
</tr>
<tr>
<td><strong>Old subjects</strong></td>
<td></td>
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</tr>
<tr>
<td>Median RT in rested condition</td>
<td>335 ± 27.7</td>
<td>358.5 ± 29.36</td>
<td>363.5 ± 31</td>
<td>383 ± 30.69</td>
<td>412.5 ± 31.48</td>
<td>405 ± 33.95</td>
</tr>
<tr>
<td>Median RT in SD condition</td>
<td>339 ± 32.67</td>
<td>353 ± 40.16</td>
<td>347 ± 49.17</td>
<td>391 ± 38.06</td>
<td>366 ± 46.18</td>
<td>400.5 ± 61.17</td>
</tr>
<tr>
<td>Lapses in rested condition</td>
<td>5 ± 6.89</td>
<td>12.5 ± 6.94</td>
<td>15.5 ± 6.54</td>
<td>13.5 ± 8.22</td>
<td>20 ± 8.56</td>
<td>23 ± 8.73</td>
</tr>
<tr>
<td>Lapses in SD condition</td>
<td>7 ± 7.25</td>
<td>12.5 ± 7.54</td>
<td>12.5 ± 9.76</td>
<td>14.5 ± 8.01</td>
<td>11.5 ± 11.05</td>
<td>17.5 ± 12.87</td>
</tr>
</tbody>
</table>

Lapses

ANOVA. Median values and standard errors are presented in Table 2. We transformed number of lapses according to Dinges’ recommendations (Dinges et al., 1997) to convert our data in a normal distribution. A three-factor repeated measures ANOVA with category, condition and session as main explaining factors showed a significant effect for sleep deprivation ($F = 8.6, P = 0.009$) and time of testing ($F = 4.2, P = 0.005$). An interaction between time of testing and category ($F = 3.3, P = 0.017$) and between condition and category ($F = 3.97, P = 0.06$) was also observed.

Negative binomial regression. We then evaluated the risk of having lapses according to the age group and the sleep deprivation. A negative binomial regression using number of lapses per session per subject as dependent variable and age (older versus young), sessions and sleep condition (rested versus sleep deprived) as determinants, clustered on subjects showed a significant effect for age and sleep condition.

Overall, older subjects increased by 3.9 times (95% CI 1.5–9.8) the risk of lapses compared with young subjects ($P < 0.004$). Sleep deprivation also increased by 1.9 times (95% CI 1.3–2.7) the risk of lapses ($P < 0.001$).

Young subjects. A negative binomial regression using number of lapses per session per subject as dependent variable and age (older versus young), sessions and sleep condition (rested versus sleep deprived) as determinants, clustered on subjects, showed a significant effect for sleep condition.

Sleep deprivation increased by 1.9 times (95% CI 1.3–2.7) the risk of lapses ($P < 0.001$).

Older subjects. A negative binomial regression using number of lapses per session per subject as dependent variable and sessions and sleep condition (rested versus sleep deprived) as determinants, clustered on subjects showed a significant time effect.

Lapses increased by 1.14 times (95% CI 1.0–1.3) per session over the six sessions ($P < 0.008$).

Figure 1 show the cumulative number of lapses (addition of 10 subject’s score) across time and sessions for young and older subjects.

Relationship between fatigue, sleepiness and performances

There was no relationship between fatigue or sleepiness and performances (median RT and lapses) in young subjects. In older subjects, sleepiness was not correlated to performances but lapses and RT were significantly correlated with the perception of fatigue (Spearman’s $\rho = 0.73$, $P < .05$ and $0.648$, $P < 0.05$, respectively).

Self-perception of performances

Overall population

There was a significant decrease in the self-evaluation of performances between the rested and sleep restricted condition (69.6 ± 16.0 versus 52.7 ± 18.4, $P < 0.001$).

Young subjects

There was a significant decrease in the self-evaluation of performances between the rested and sleep restricted condition (67.4 ± 18.7 versus 50.7 ± 23.4, $P < 0.01$).

Older subjects

There was a significant decrease in the self-evaluation of performances between the rested and sleep restricted condition (71.4 ± 13.5 versus 54.6 ± 12.5, $P < 0.003$).

Figure 2 shows on a similar scale the proportional decrement of performances (lapses), self-evaluation of performance and alertness after sleep deprivation for both age groups.
DISCUSSION

As expected from previous studies, we found that age had a very negative effect on performance (Wilkinson and Allison, 1989). The fact that older subjects had worse baseline performance than young subjects confirms the validity of our measurements.

Sleep deprivation also affected daytime vigilance and performance in our overall population, which was also very much as expected according to previous findings (Dinges et al., 1997; Van Dongen et al., 2003).

Our results confirm those of previous studies of the differences between young and older subjects under sleep deprivation (Brendel et al., 1990; Smulders et al., 1997).

Young subjects’ RTs are significantly better than those of older subjects when rested. However, sleep deprivation affects significantly the young whereas older subjects do not alter their performances significantly.

Our study bring new findings on perception of performances under sleep deprivation. Even if both groups of subjects estimated that their performances would be impaired after sleep deprivation to a similar degree, only the younger ones significantly impaired their real performances, while the older subjects did not show any significant variation after sleep deprivation (see Fig. 2).

We hypothesize, therefore, that performance evaluation as well as level of sleepiness could depend on a different physiological component (i.e. homeostatic pressure) (Achermann et al., 2001) than actual RT.

Self-perception of impairment associated with unaffected performances under sleep loss in old subjects or non-perception of performance decrement in young subjects could explain a lower risk of involvement of older subjects compared with young drivers in sleep-related accidents (Connor et al., 2002).

Self-perception of fatigue in the older group seems to be a better predictor of performance decrement over time than sleepiness. Under sleep deprivation young subjects express a much higher degree of fatigue than older ones even if young subjects maintain a better absolute performance (number of lapses). Fatigue therefore seems more an indicator of age-related performance decrement instead than an absolute marker of performance.

Because RT is an important component of adaptative responses in real world activities (i.e. automobile driving) one could speculate from our results that sleep-related accidents do not simply affect young drivers because of a higher exposure of this age group to sleep restriction, but also because of a higher sensitivity to sleep loss or an overestimation of performance.

ACKNOWLEDGEMENTS

This study was supported by Conseil Régional d’Aquitaine Research Fund.

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