Patients with chronic obstructive pulmonary disease (COPD) present with impairments of their cognitive performance. It is still unknown whether cognitive deficits influence driving abilities in patients with COPD. The present study investigates driving performance in patients with COPD and healthy controls. Driving simulation was performed in 17 patients with COPD and 10 healthy controls. Patients with COPD demonstrated significantly worse results in terms of accident frequency in the simulated driving situation. No correlations existed between the severity of disease, assessed from the polysomnographical findings (e.g., lung function, blood gas analysis, sleep disturbance, nocturnal ventilation, and oxygen saturation), and driving performance. We conclude that impairments of driving performance in patients with COPD cannot be predicted on the basis of the severity of the disease. The impairment of driving performance in the simulated driving situation in COPD patients may have crucial consequences for driving licensing in these patients.

Key words: cognitive deficits, chronic obstructive pulmonary disease, driving performance, driving simulator tests

INTRODUCTION

Cognitive impairment is known to affect a large number of patients with chronic obstructive pulmonary disease (COPD). COPD patients experience declines in a
number of cognitive functions such as reaction time (1, 2), short- and long-term memory (2-4), abstract reasoning skills (2) and complex visual motor processes (5). Apart from these intellectual aspects deficits with regard to simple motor movements, strength, and perceptual motor integration are described (2, 6-9).

Presumably chronic reduction of arterial oxygen pressure significantly contributes to these deficits. Even in healthy persons acutely induced hypoxemia causes profound changes of neuropsychological variables such as impairments of concentration, short-term memory, learning processes, motor speed and verbal fluency (10-12). At high altitudes, even healthy persons show a significant reduction of reaction times and behavior disorders (13-16). Patients with profound and long lasting hypoxemia exhibit reductions of memory capacities (16, 17).

But even mildly hypoxemic COPD patients demonstrate reduction in neuropsychological functioning. Prigatano et al (2) demonstrated consistent deficits in abstract reasoning, memory, and speed of performance in a group of 100 mildly hypoxemic COPD patients (mean PaO\textsubscript{2}: 66.3 mmHg) as compared with 25 matched equated healthy controls. Similarly, Grant et al (6) found changes in higher cerebral functions in mildly hypoxemic COPD patients (mean PaO\textsubscript{2}: 67.8 mmHg) and a correlation between the degree of impairment and severity of hypoxemia. The dependency between cognitive performance and degree of hypoxemia has also been shown in that study.

Attention is a major aspect contributing to cognitive performance and it resembles a process of selection and reduction of recognition on relevant aspects. The major aspects of attention which can be distinguished are: simple, selective, divided attention, vigilance, and sustained attention. In a previous investigation, we compared neuropsychological performance of 32 patients with COPD and 10 healthy controls. There were no differences between COPD patients and controls with regard to divided attention and vigilance. However, COPD patients showed significantly worse results in terms of simple, selective, and sustained attention. No correlation existed in this study between the severity of the disease (lung function, blood gas analysis, nocturnal oxygen saturation) and neuropsychological impairment (18).

Different attentional aspects are crucial to car driving performance. Simple attention is relevant in terms of breaking reactions. Divided attention resembles driving in a city with much traffic, and vigilance is engaged when the driving situation is long-term under monotonous conditions. Motor vehicle accidents are one of the major causes of death in modern society (19). Factors, such as excessive speed or alcohol consumption are primary and obvious causes of accidents (20). Furthermore, it is known that patients with obstructive sleep apnea have up to 7-fold increased accident risk (21-24) and that CPAP therapy is an adequate tool in reducing accident frequency in these patients (25-29).

There is no information about accident frequency in patients with COPD. Additionally, there are no legal considerations about how to deal with COPD
patients regarding their driving licensing. Recommendations concerning the ability to drive a car consider disturbances of gas exchange (e.g., global respiratory insufficiency) or syncope due to coughing as possible risk factors for impaired driving abilities (30), but there are no legal recommendations about how to deal with these patients as far as driving licensing is concerned.

The present study was conducted in order to evaluate driving capacity in a simulated driving situation in patients with COPD compared with healthy controls. Furthermore, the study investigated whether there are predictors (e.g., disease severity, disturbances of sleep architecture, or nocturnal ventilation) for accident or concentration faults.

**MATERIAL AND METHODS**

The study was approved by the Ethics Committee of the Ruhr-Universität in Bochum (Germany) and all patients and controls gave their written and informed consent prior to the study. Subjects were instructed to avoid caffeine and alcohol during the study period. They were also informed that all results were confidential, had no legal impact, and no influence on their driving license. All participants of the study were active drivers.

**Subjects**

A total of 17 consecutive patients (age 55.2 ±9.3 years) with COPD in a stable phase of their disease (at least 4 weeks after recovery from exacerbation of COPD, without any clinical hints for a new exacerbation) were investigated. The results were compared with those from 10 healthy controls (age 55.1 ±7.8 years) in which COPD was excluded clinically. In both groups, obstructive sleep apnea was excluded polysomnographically (Alice IV; Respironics®, Pittsburg, KS, USA).

Exclusion criteria were as follows: obstructive sleep apnea, cerebral diseases (head injuries, cerebral ischemia, and encephalitis), central nervous stimulating or relaxing medication, alcohol or drug abuse, and disability to drive a car.

Patients and controls underwent a driving simulator test. The C.A.R.* (Computer Aided Risk Simulator; Ing. R. Foerst, Gummersbach, Germany) was used in conjunction with the German traffic board (Deutscher Verkehrsrat) in order to examine its clinical relevance. In a former study, we could demonstrate a significant reduction of concentration faults and accidents with this simulator in patients with obstructive sleep apnea syndrome before and under CPAP (continuous positive airway pressure) therapy (30). At present, the maximal number of errors that should be tolerated (normative data) is under debate. In brief, sitting in the simulator, after a trial period of 15 min, subjects have to drive on a highway for 60 min with a mean speed of 100 km per h. Monotonous conditions, despite weather changes (rain, sunshine, snow, and mist), and daytime conditions are presented in a random sequence on a computer screen. Obstacles (deer, pedestrians, and other vehicles) occur infrequently, randomized by the computer. Drivers experience real car reactions (e.g., aquaplaning during rain conditions, feedback by automobile noise, and reaction of the car seat to speeding and slowing down).

Computer analysis of the simulator only scores accidents (i.e., crashes with other cars, pedestrians, and other obstacles, or driving off the road) and some concentration faults (e.g., using the headlights). In order to evaluate all concentration deficits (e.g. driving with headlights switched off at night, driving with headlights switched on during daytime, disregarding the speed limit, driving with dimmed headlights, tracking error such as turning too extensively to the right or left
side of the road, touching the curb or the opposite lane, not using the flash of headlights, disregarding traffic lights, and disregarding right of way) a technician watches the road situation on a video screen and observes the patient from behind, registering all the concentration faults manually. All these items represent important errors, because they can lead to near-miss accidents. The technician was not allowed to motivate the patient, but can take action if problems with handling the simulator occur.

In both patients and normals, the testing was performed either between 09.00-11.00 h or between 16.00-18.00 h, according to the circadian rhythm and representing the daytime periods in which alertness is highest.

Statistical analysis

Comparisons between controls and COPD patients were performed with a t-test for variables with normal distribution and with Mann-Whitney-Rank-Sum-test for variables without normal distribution. Multivariate analyses were carried out with multiple linear regression analyses (backward selection, inspiratory pressure 0.05, and outflow pressure 0.1). Dependent variables in this analysis were accident frequency and frequency of concentration faults. The following independent variables were investigated: sleep architecture (arousal-index, stages sleep 1-4, and rapid eye movement sleep), and ventilatory parameters (apnea-hypopnea-index, oxygen saturation). In cases with significant associations, univariate regression analyses were performed. Statistical significance was assumed when P<0.05.

RESULTS

Table 1 shows the results of the lung-function tests in patients with COPD. Although they were in a stable phase of their disease, being without an exacerbation (cough, increased sputum) patients had airway obstruction corresponding to GOLD stage II-III and considerable hyperinflation of their lungs. Blood gas analysis at rest revealed no hypoxemia and no hypercapnia.

Table 2 shows the polysomnographical results and the nocturnal oxygen saturation of COPD patients and controls. In COPD patients sleep architecture was significantly worse in terms of reduced S3/4 sleep (COPD: 5.7 ±4.3 % vs. controls: 18.5 ±6.1 % of total sleep time, P<0.001) and increased S1/S2 sleep (COPD: 30.6 ±13.5 vs. controls: 8.4 ±5.6 % of total sleep time, P<0.001). Analysis of nocturnal ventilation revealed the absence of sleep apnea syndrome in both COPD patients and controls. However, patients with COPD showed significantly increased incidence of sleep-related hypoventilation (AHI in COPD: 13.3 ±8.1/h vs. controls: 5.6 ±6.3/h, P<0.05). With regard to nocturnal oxygen saturation, patients with COPD and controls had a comparable mean oxygen saturation; but minimum oxygen saturation was significantly lower (COPD: 85.5 ±5.9% vs. controls: 90.0±2.3%, P<0.01) and time of oxygen saturation below 90% of total registration time was significantly longer in patients with COPD (COPD: 33.3 ±38.5 vs. controls: 0.2± 0.2%, P<0.01).

Figs. 1 and 2 show the results of the driving simulator test in patients with COPD compared with controls. Both groups committed a high number of
Table 1. Lung function and blood gas analysis in patients with COPD (n=17).

<table>
<thead>
<tr>
<th></th>
<th>COPD (n=17)</th>
<th>Controls (n=10)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rt (kPa/l/s)</td>
<td>6.6 ±2.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEV₁%IVC (% pred.)</td>
<td>52.5 ±12.9</td>
<td></td>
<td></td>
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<tr>
<td>MEF₅₀ (% pred.)</td>
<td>11.9 ±8.5</td>
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<td></td>
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<tr>
<td>MEF₂₅ (% pred.)</td>
<td>9.0 ±4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ITGV (% pred.)</td>
<td>172.2 ±43.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RV%TLC (% pred.)</td>
<td>164.8 ±34.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PaO₂</td>
<td>68.9 ±8.5</td>
<td></td>
<td></td>
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<tr>
<td>PaCO₂</td>
<td>40.3 ±5.8</td>
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</table>

Table 2. Polysomnography and nocturnal oxygen saturation in patients with COPD and controls.

<table>
<thead>
<tr>
<th></th>
<th>COPD (n=17)</th>
<th>Controls (n=10)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>REM (%)</td>
<td>12.5 ±5.9</td>
<td>12.9 ±5.0</td>
<td>NS</td>
</tr>
<tr>
<td>S3/S4 (%)</td>
<td>5.7 ±4.3</td>
<td>18.5 ±6.1</td>
<td>&lt;0.001</td>
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<tr>
<td>Wake (%)</td>
<td>30.6 ±13.5</td>
<td>8.4 ±5.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Arousal-Index (/h)</td>
<td>12.5 ±13.8</td>
<td>15.6 ±8.6</td>
<td>NS</td>
</tr>
<tr>
<td>Apnea-Index (/h)</td>
<td>2.9 ±0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apnea-Hypopnea-Index (/h)</td>
<td>13.3 ±8.1</td>
<td>5.6 ±6.3</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>SaO₂m (%)</td>
<td>92.4 ±1.9</td>
<td>94.3 ±2.6</td>
<td>NS</td>
</tr>
<tr>
<td>SaO₂min (%)</td>
<td>85.5 ±5.9</td>
<td>90.0 ±2.3</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>t90 (% total registration time)</td>
<td>33.3 ±38.5</td>
<td>0.2 ±0.2</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

SaO₂m = mean oxygen saturation, SaO₂min = minimum oxygen saturation, t90 = duration of oxygen desaturation below 90%; NS = nonsignificant.

Fig. 1. Frequency of (A) concentration faults and (B) accidents in the simulated driving situation in COPD patients and control subjects.
concentration faults and interindividual comparison revealed no significant
differences between COPD patients and controls (COPD: 8.5 ±4.7 vs. controls:
7.1 ±3.2, NS). As far as accident frequency in the simulated driving situation was
concerned, COPD patients caused significant more accidents than controls
(COPD: 3.9 ±2.7 vs. controls: 1.3 ±1.5, P<0.01).

Multiple linear regression analysis revealed no significant associations
between polysomnographic parameters (neither sleep architecture nor ventilatory
parameters), lung function data, and nocturnal oxygen saturation, on the one side
and driving performance, on the other side (data not shown). Thus, there were no
predictors for faults and accidents on the basis of disease severity or severity of
ventilation during sleep.

DISCUSSION

The present study demonstrates that in patients with COPD the frequency of
accidents is increased in a simulated driving situation, as compared with healthy
controls. No relationship could be established between the disease severity,
expressed in lung function, blood gas analysis, disturbances of sleep architecture
or breathing during sleep, on one side and driving performance, on the other side.

Sleepiness is a major contributing factor to road traffic accidents and is often
ignored because the accident seems to be attributable to other more obvious
causes, such as alcohol, bad weather, or impairment due to drug abuse. Accident
frequency can be evaluated by different tools, e.g., clinical history, analysis of
databases of insurance companies, legal authorities, neuropsychological testing,
and driving simulation. There are well investigated clinical conditions causing
daytime sleepiness and consecutively increased accident frequency. It has been
shown that patients suffering from obstructive sleep apnea syndrome have a 2-7-
fold increase in the incidence of accidents (21-24) and that the frequency of
accidents can be significantly reduced by adequate CPAP-therapy (25-29).

In cases of obstructive sleep apnea, physicians are often asked to make
recommendations about the individual’s ability to drive a car, especially after
initiating CPAP therapy. This is of special interest, because until now no clear
predictors for accident frequency, e.g., in terms of polysomnography respectively
nocturnal oxygen saturation have been identified.

Only a few studies have investigated the neuropsychological sequelae associated
with COPD. In summary, deficits of flexible and abstract thinking, perceptual
motor integration, simple motor reactions, and memory capacities have been shown
(31-33). In a former study, we could demonstrate worse results in COPD patients in
terms of simple, selective, and sustained attention. No correlation existed in that
study between the severity of disease (lung function, blood gas analysis, and
nocturnal oxygen saturation) and neuropsychological impairment (18).
In most studies, hypoxemia is blamed for the existing neuropsychological deficits. However, until now there is no clear evidence that there is a relationship between the degree of hypoxemia and the degree of cognitive impairments. Disruption of sleep is a second factor which is also blamed for neuropsychological deficits. In patients with COPD, disruption of sleep has been shown in terms of shortened sleep duration and reduction of Stage 3 and 4 sleep. Furthermore, it has been demonstrated that oxygen supplementation leads to an improvement of sleep architecture (34, 35).

Although much is known about neuropsychological deficits in COPD and the possible reasons for them, there are until now no studies about accident frequency or driving performance in patients with COPD. Thus, there are no legal recommendations about how to deal with patients suffering from COPD especially those who need long-term oxygen therapy. Car driving is a situation in which several attentional aspects (e.g., simple and selective attention and vigilance) are engaged. Accident frequency can be investigated by different diagnostic tools. In the present study, we choose the simulator C.A.R®. The simulated driving situation covers all attentional aspects engaged in car driving. The main aspect engaged is vigilance which is important in long term driving under monotonous situations (1).

In the present study we could demonstrate that accident frequency is increased in COPD patients, as compared with healthy controls. Although the number of investigated patients is small, the study gives hints to driving impairment in COPD. Additionally, there are no hints that disease severity, impairment of sleep architecture, or disturbance of nocturnal ventilation might serve as predictors for driving performance. These findings, which have to be underlined by further studies in lager population samples of both COPD patients and controls, might have impact on legislation dealing with driving licensing in patients with COPD.

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