Investigating the Effects of Continuous Positive Airway Pressure (CPAP) Treatment on Driving and Attentional Performance of Patients with Sleep Impairments

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***Abstract*— Sleep apnea syndrome (SAS) may increase the risk for serious injury and accidents while driving. Although studies have shown (using subjective measures) that sleep apnea could be a serious risk factor for motor vehicle accidents (MVAs), currently no exact statistics and objective measures exist that define this risk. Furthermore, it has not yet been established whether treatment of SAS using continuous positive airway pressure (CPAP) reduces the risk for MVAs and what is the required treatment period before a SAS patient is considered fit to drive. In the present study, therefore, we investigated the risk of MVAs for SAS patients and the effects of CPAP treatment on this risk. Specifically, we compared healthy controls and SAS patients before and after CPAP treatment on a series of attentional tests and two different driving tasks on a vehicle simulator. Preliminary results demonstrated that untreated SAS patients had more MVAs, maintained higher mean speed, and were involved in higher lane deviation variability in the simulated driving tasks as compared to treated patients and healthy controls. Overall, these preliminary data suggest that SAS is a serious risk for MVAs that can be reduced by CPAP treatment, thus European driving regulations should be adjusted accordingly for SAS patients that wish to drive.**

I. Introduction

Motor vehicle accidents (MVAs) represent one of the major causes of death and serious injury in today's society [1]. MVAs are usually associated with speeding and/or alcohol consumption [2]. However, driver's fatigue that leads to sleepiness [3] should also be considered as possible MVA risk. The effects of sleepiness on people's driving performance, and thus to MVAs, is generally believed to be underestimated since no exact statistics are recorded by officials in the case of an accident [4-5]. Nevertheless, the incidence of MVAs due to sleepiness is an important risk factor that needs to be investigated in order to make driving a safe experience for everyone.

Sleepiness while driving is most commonly experienced by people suffering from the sleep apnoea syndrome (SAS; e.g., [6-7]). SAS is a medical disorder that is characterized by repetitive reductions (hypopnoeas) or pauses (apnoeas) in breathing during sleep due to upper airway narrowing or closure. These respiratory events can vary from a few seconds to minutes, depending on the severity of the syndrome, and are terminated by a brief awakening (which restores normal breathing). During the sleep of a SAS patient, this circle between hypopnoeas/apnoeas and awakening is repetitive, thus leading to fragmented sleep and excessive daytime sleepiness [8].

A large number of subjective (i.e., self-report) and objective (e.g., insurance/police records) studies have looked at the prevalence of MVAs for SAS patients (e.g., [9-11]). The majority of these studies have suggested that SAS presents an increased risk factor for MVAs. However, these results have been criticized due to confounding variables (e.g., sex, age, driving experience) and the possible biases that could have inadvertently affected the outcomes (i.e., informational, recall, and selection bias; cf., [4]).

In order to obtain an accurate measure regarding the risk of MVAs for SAS patients, researchers have turned to experimental testing using various types of off-road driving simulators. Results from these studies have shown that patients with SAS have an increased accident rate in driving simulation tasks (e.g., [9, 12-15]), which can be estimated at around 2- to 7-times higher as compared to normals (e.g., [4-5, 14, 16]). It has also been reported that SAS patients exhibit slower reaction times (RTs) than controls in avoiding obstacles on the road, resulting in 4 times more object collisions than controls [14]. In addition, it has recently been demonstrated that SAS patients perform poorer than normals in steering ability (i.e., "tracking error"; [9, 12]) with half of the patients being worse than any one control participant [9]. Finally, the research conducted to-date have concluded that the SAS patients face an increased difficulty in sustaining attention while driving, thus exhibiting poorer performance and lower vigilance during experimental testing involving driving on a monotonous highway (e.g., [3, 9, 12]).

Overall, the research evidence presented strongly suggests that patients suffering from SAS have a higher risk of MVAs as compared to their healthy counterparts. The question that arises, therefore, is: "Should the SAS patients be considered fit to drive?". Given that driving is an essential part of everyday life for the majority of people, a series of treatments have been develop, in order to assist SAS patients in driving and other daily functions. Although treatments do exist, it is difficult for a clinician to advice a SAS patient whether each particular treatment is effective or not for him/her and what is the required treatment period that he/she has to undergo in order to be fit to drive. Thus, a proper evaluation of these issues is necessary.

Continuous positive airway pressure (CPAP) represents the most commonly used treatment and is considered as the most effective one [17-18]. CPAP is a device placed by the patient's bedside that generates air pressure and delivers it through a sealed face-mask, thus opening the patient’s upper airway during sleep (e.g., [19]). CPAP, therefore, prevents the recurrent upper airway obstruction during sleep and is most effective when used regularly [2].

Studies have shown that CPAP treatment can reduce the number of MVAs in SAS patients, both in simulated driving [14] and real-life situations (e.g., [9, 17-18, 20]). Specifically, studies have shown that regular use of CPAP improves self-reported [17-18] and objective MVA rates [20-21]. For example, in a self-report study of 59 drivers, Cassel et al. [17] reported a decrease from 0.8 to 0.15 accidents per 100,000 km driven after CPAP treatment. More recently, it has been shown that in 36 SAS patients undergoing CPAP treatment, a marked reduction in objective MVA reports over a period of 2 years was noted, while in 14 SAS patients who denied treatment the accident rate remained constant [20]. Similarly, George [21] reported that individuals treated for 3 years with CPAP had a decrease in objectively measured MVAs, such that 75 accidents were avoided in 210 patients [20]. Finally, Yamamoto et al. [18] reported that a remarkable reduction of excessive daytime sleepiness and driving errors was observed for over a year after initiation and continuation of the CPAP treatment by SAS patients.

More importantly, it has been suggested that CPAP may effectively reduce the MVA risk of SAS patients in experimental tests conducted during simulated driving (e.g., [14, 22]). Note, however, that the task in some of these studies was actually a choice reaction task that required sustained vigilance rather than a simulated driving task. For example, George, Boudreau, & Smiley [9] tested 21 SAS patients in order to assess the effects of CPAP treatment on a divided attention driving task. All of the patients were treated with CPAP and 17 of them were retested after 1-12 months after treatment. 18 control participants were also tested and retested after 2-12 months time. The authors concluded that CPAP treatment resulted in a significant improvement in patient performance as compared to the pre-treatment performance. However, the results regarding the patient performance as a function of post-treatment duration were inconclusive.

Another study conducted by Orth et al. [2] compared the driving performance between 10 healthy controls and 31 SAS patients before, 2, and 42 days after initiation of CPAP treatment. The results showed that the driving performance before treatment was significantly worse in SAS patients as compared to healthy controls, especially in terms of accident frequency and concentration faults. However, after initiation of CPAP treatment, the accident rates and concentration faults were lowered significantly for both the short- and long-term treatment duration. Alertness and divided attention were also improved for the treated participants.

More recently, Turkington et al. [3] set-out to examine directly the time course changes on driving performance during and after cessation of CPAP treatment on SAS patients. 18 patients conducted a divided attention simulator task during a 2-week trial (tested in days 1, 3, and 7) of CPAP and after cessation of CPAP treatment (tested in days 1, 3, and 7). The authors reported that the patients’ driving performance improved rather quickly with CPAP treatment throughout the duration of the 2-week treatment, while discontinuation of the treatment led to a 7-day performance preservation, which was then followed by a sharp decline.

The past research reviewed here suggests that SAS may be a significant contributing factor to MVAs. One could argue, however, that several limitations present in these studies may render their results inconclusive. For instance, the majority of these studies have utilized a single, brief practice session for the simulated driving task, which may not have allowed the patients to familiarize themselves with the task. In addition, previous studies have not taken into consideration the issue of correct patient diagnosis (e.g., it should be clear that the person is actually suffering from SAS and is not just fatigued) and the circadian circle influence on performance (e.g., the time of testing could affect performance; i.e., night versus morning testing sessions). Finally, a major limitation can be identified in the choice of experimental methodology that may have lead to inaccurate conclusions (e.g., conflicting results, measurements of brief post- and pre- CPAP treatment periods, manual scoring).

On the whole, research to-date identifies SAS as a significant risk factor to MVAs and supports that treatment of SAS using CPAP can reduce this risk. As yet, however, there are no generally accepted regulations within the Europe Union concerning driving licensing and SAS. Thus, it seems pertinent that these regulations are established both for the benefit of the SAS patients and the safety of all drivers. In the present study, therefore, we set-out to investigate the objective risk of MVAs for SAS patients and to measure whether or not CPAP can significantly reduce this risk. In order to accomplish this, we compared the performance levels of SAS patients before and after receiving CPAP treatment and healthy participants in a series of simulated driving and attentional tasks.

II. METHODS

A. Participants

A total of 20 male participants (10 in each experimental group; mean age of 53 years) took part in the experiment. All of the participants were experienced and currently active drivers (at least 3 years after obtaining their driving license with an annual mileage greater than 10,000 km). All of the patients were selected from a medical clinic and they had to be diagnosed with SAS with a sleep apnea index greater than 10. The patients took part in the experiment when not receiving any treatment for at least 7 days and after receiving CPAP treatment for at least 7 days. Healthy participants were also medically examined in order to ensure that they were not suffering from SAS and that they did not have any medical problem or alcohol/drug abuse.

B. Materials

I) Dynamic driving simulator tasks: The driving tasks were conducted in a driving simulator built around a Smart cabin equipped with sensors (see Fig. 1A). The position of all control levers and ignition key were transmitted to a desktop computer. All operational elements, steering wheel, accelerator pedal, brake pedal, gearshift lever, and handbrake lever provided nature-true force reactions. The sight system included 5 large-screens, each having a width of 2 m. There was on-screen projection with consumer video projectors with 2500 ANSI-lumen. The sound system generated original sounds according to the situation (starter, engine noise, screeching of tires, drive wind, etc.). The vibration device created nature-true vibrations of the vehicle according to the revolvation of the simulated engine.

Fig. 1 A. The Smart cabin of the driving simulator used in the experiment. B. A sample screen of the "Car Following" scenario.

The experiment required the participants to complete two different tasks with the driving simulator, the "Lane Tracking" and the "Car Following" scenario. The "Lane Tracking" scenario required the participant to drive on the right side of the road and maintain a constant speed of about 80 km/hr. The "Car Following" scenario required the participant to drive on the right side of the road and follow the vehicle driving in front of them (see Fig. 1B). Participants were asked to hold a constant distance from the front vehicle so that they do not lose, hit, or pass it. The front vehicle drove at 90 km/hr with sudden decelerations to 30 km/hr, accelerations, or braking (braking lights of the front vehicle illuminated) at random points during the drive. The scenario order was counterbalanced and each scenario lasted approximately 20 min with the drivers covering an approximate distance of 26 km.

II) Attentional tasks: Neurocognitive performance was assessed by a set of computer-assisted psychological tests (Test for Attentional Performance, TAP, version 2.1; [23-24]). The core of the procedures comprised of RT tasks of low complexity. The tasks consisted of simple and easily distinguishable stimuli to which the participants reacted by simple motor responses (i.e., pressing a custom made key). The tests selected to evaluate cognitive functioning during the experiment were a) alertness, b) divided attention, and c) go/no-go.

C. Procedure

Before the testing day, participants were medically examined in order to ensure correct SAS diagnosis and evaluation of other health problems. All testing took place in the afternoon hours, thus avoiding performance differences due to circadian influence. Before testing, all of the participants had to take a drug urine test and breath alcohol test. In the case of a positive drug or alcohol test, the participants were not allowed to continue with the experiment.

I) Dynamic driving simulator tasks: Initially, the participants were required to complete a series of practice sessions, which were 5 min versions of the experimental scenarios, in order to ensure familiarity with the experimental setting and task.

Upon completion of the practice sessions, participants returned to the testing site to complete the experimental task. The patients had to visit the testing site at two different occasions, one before and one after receiving CPAP treatment (the order was counterbalanced). The "Car Following" and "Lane Tracking" scenarios were completed with a break in between the sessions (the order was counterbalanced).

II) Attentional tasks: After the completion of the driving scenarios, participants completed the attentional tasks on alertness, divided attention, and go/no-go (the testing order was counterbalanced). During the alertness task, participants were assessed in their ability to maintain high levels of responsiveness in anticipation of a target stimulus (e.g., [25]). Performance was measured by the participant's RTs in response to a visual target stimulus (i.e., the presentation of a cross). The participants completed 3 blocks of 20 trials each and they were informed that they had to respond within 2 secs, otherwise the test would automatically prompt them that a response was not recorded. The participants were also informed that if they responded too fast (RT less than 100 msec) or did not respond (RT greater than 2 sec) the trials would be repeated.

In the divided attention task, participants were assessed in their ability to attend to two different sensory stimuli. Participants had to attend to a visual and an auditory stimulus simultaneously. The visual task consisted of crosses that appeared in a random configuration in a 4x4 matrix and the participant had to detect whether or not the crosses formed the corners of a square. The auditory task was composed of a regular sequence of high and low beeps and the participant had to detect an irregularity in the auditory sequence. In order to establish a baseline, a control condition was also included in which participants performed a visual-only and an auditory-only task. The participants completed 3 blocks with the number of trials for the visual discrimination task being set to 100 and 200 for the auditory task.

Finally, in the go/no-go task the participants had to react selectively to one class of visual stimuli but not to others, thus assessing their ability to suppress wrong responses to irrelevant stimuli, as well as determining the RT under conditions of stimulus selection.

III. RESULTS

I) Driving task performance: During the "Car Following" scenario, the SAS patients without treatment were involved in 7 crashes (made by different participants), while after receiving CPAP treatment the patients were involved in only 2 crashes. The control participants did not have any accidents.

T-test comparisons revealed that significant differences were obtained in the speed, speed variance, and lane deviation variance measures. Specifically, SAS patients before treatment (M=85.62 km/hr) maintained a higher mean speed as compared to when they were receiving CPAP (M=76.70 km/hr; $t(9)=2.45$, $P<.001$) and as compared to the speed maintained by the control group (M=77.80 km/hr; $t(9)=2.42$, $P<.001$; see Fig. 2A). The same was not true for speed variance, where controls (M=29.90; $t(9)=2.21$, $P<.05$) and CPAP treated patients (M=24.32; $t(9)=2.65$, $P<.01$) exhibited higher speed variability than SAS patients (M=12.20; see Fig. 2B). Finally, SAS patients (M=0.47) exhibited higher lane deviation variability as compared to controls (M=0.34; $t(9)=3.39$, $P<.001$), while no other differences were found (see Fig. 2C).

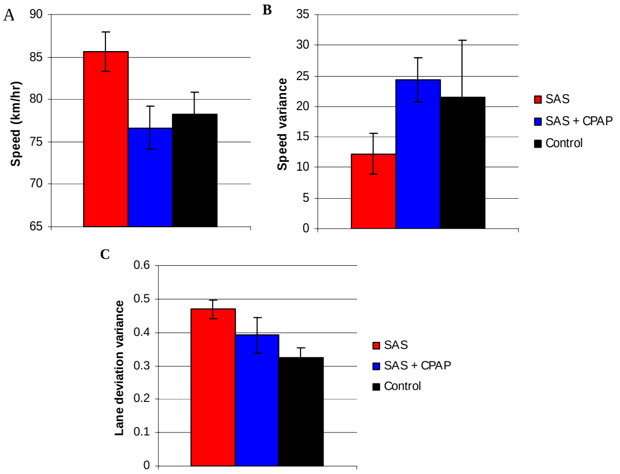

Fig. 2 Comparison of the performance of the control group and the SAS group before and after CPAP treatment in the "Car Following" scenario as a function of A. Speed, B. Speed variability, and C. Lane deviation variability.

During the "Lane Tracking" scenario, t-testing revealed significant differences only for the speed and lane deviation variability measures. Specifically, SAS patients before treatment (M=97.88 km/hr) maintained lower mean speed as compared to the control group (M=115.86 km/hr; $t(9)=2.83$, $P<.01$; see Fig. 3A). Finally, similar to the "Car Following" scenario, SAS patients (M=0.55) exhibited higher lane deviation variability as compared to controls (M=0.40; $t(9)=2.71$, $P<.01$), while no other differences were found (see Fig. 3B).

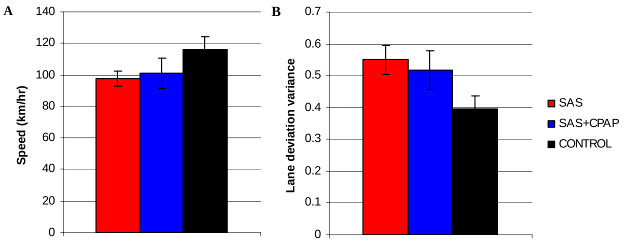

Fig. 3 Comparison of the performance of the control group and the SAS group before and after CPAP treatment in the "Lane Tracking" scenario as a function of A. Speed and B. Lane deviation variability.

II) Attentional task performance: Statistical analysis of the attentional performance of the participants resulted in significant differences only for the divided attention test. No significant differences were noted for the alertness and the go/no-go tasks. In particular, the analysis for the divided attention task revealed a significant main effect for Modality (auditory vs. visual vs. audiovisual stimuli; $F(2,18)=69.58$, $P<.001$), while no main effect of Group (SAS vs. SAS+CPAP vs. Control; $F(2,18)<1$, n.s.) and no Modality x Group interaction was obtained ($F(4,36)<1$, n.s.). The significant main effect of Modality revealed that participants were significantly faster for auditory stimuli (M=557 ms) as compared to audiovisual stimuli (M=796 ms; $P<.001$). In addition, participants were significantly slower when presented with visual stimuli (M=957 ms) as compared to the latencies when the participants were presented with auditory and audiovisual stimuli ($P<.001$; see Fig. 4).

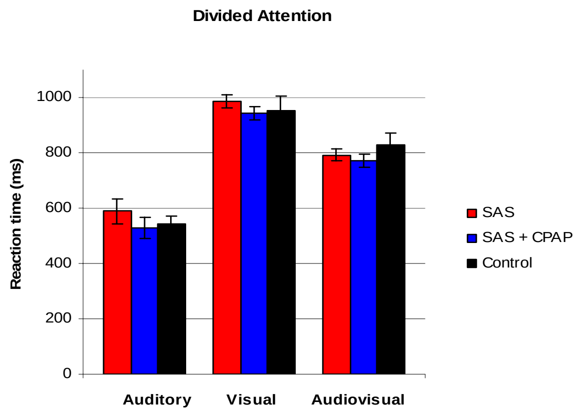

Fig. 4 A comparison of the performance of the control group and the SAS group before and after CPAP treatment on the divided attention task.

IV. DISCUSSION

Overall, it appears that there are indeed some important differences between normal participants and SAS patients before and after receiving CPAP treatment. The most pronounce difference can be noted in the large number of vehicle crashes that SAS patients were involved in when they were not receiving any treatment as compared to CPAP treated patients and control participants in the "Car Following" scenario. SAS patients not receiving CPAP treatment appeared to be higher risk takers (at least for the "Car Following" scenario) since they were maintaining a mean speed that was higher than that observed in the control and treated groups tested. SAS patients not receiving CPAP also appeared to have problems in maintaining their road lane, since the highest lane deviation variability in the "Car Following" scenario was noted in their group as compared to the other two groups.

Although the data reported compose a preliminary subset of the measures evaluated in this study, some concerning differences between the groups arise. The "Lane Tracking" scenario appears to be less sensitive to performance differences than the "Car Following" scenario, however additional participant testing might result in differential sensitivity. The same holds true for the attentional tests completed. We strongly believe that additional testing of both control participants and SAS (treated and untreated) patients will eliminated these differences.

IV. Conclusions Acknowledgment

Increasing road safety will required legislation not only regarding driving under the influence of alcohol and recreational drug impairment but also driving during and/or after the use of medicinal drugs and when suffering from particular medical conditions. The present study investigated how SAS and CPAP treatment may affect driving performance. Preliminary results indicate that patients suffering from SAS and not receiving any treatment are in higher risk of a road-related accident as compared to SAS patients receiving CPAP treatment and healthy participants.

References

[1] J. A. Horne and L. A. Reyner, "Sleep related vehicle accidents," British Medical Journal, vol. 310, pp. 565-567, 1995.

[2] M. Orth, H.-W. Duchna, M. Leidag, W. Widdig, K. Rasche, T. T. Bauer, J. W. Walther, J. de Zeeuw, J.-P. Malin, G. Schultze-Werninghaus, and S. Kotterba, "Driving simulator and neuropsychological testing in OSAS before and under CPAP therapy," European Respiratory Journal, vol. 26, pp. 898-903, 2005.

[3] P. M. Turkington, M. Sircar, D. Saralaya, and M. W. Elliott, "Time course of changes in driving simulator performance with and without treatment in patients with sleep apnoea hypopnoea syncrome," Thorax, vol. 59, pp. 56-59, 2004.

[4] C. F. P. George, "Driving and automobile crashes in patients with obstructive sleep apnoea/syndrome," Thorax, vol. 59, pp. 804-807, 2004.

[5] J. A. Horne and L. A. Reyner, "Vehicle accidents related to sleep: a review," Occupational Environmental Medicine, vol. 56, pp. 289-294, 1999.

[6] M. A. Hack, S. J. Choi, P. Vijayapalan, R. J. O. Davies, and J. R. Stranling, "Comparison of the effects of sleep deprivation, alcohol, and obstructive sleep apnoea (OSA) on simulated steering performance," Respiratory Medicine, vol. 95, pp. 594-601, 2001.

[7] J. Teran-Santos, A. Jimenez-Gomez, J. Cordero-Guevara, et al., "The association between sleep apnea and the risk of traffic accidents," New England Journal of Medicine, vol. 340, pp. 847-851, 1999.

[8] B. Naegele, V. Thouvard, J. L. Pepin et al., "Deficits of cognitive executive functions in patients with sleep apnea syndrome," Sleep, vol. 18, pp. 43-52, 1995.

[9] C. F. P. George, A. C. Boudreau, and A. Smiley, "Simulated driving performance in patients with obstructive sleep apnea," *American Journal of Respiratory Critical Care Medicine*, vol. 154, pp. 175-181, 1996.

[10] G. Maycock, "Sleepiness and driving: the experience of UK car drivers," Journal of Sleep Research, vol. 5, pp. 229-37, 1996.

[11] H. Wu and F. Yan-Go, "Self-reported automobile accidents involving patients with obstructive sleep apnea," Neurology, vol. 46, pp. 1254-1257, 1996.

[12] M. Juniper, M. A. Hack, C. F. P. George, et al., "Steering simulation performance in patients with obstructive sleep apnoea and matched control subjects," *European Respiratory Journal*, vol. 15, pp. 590-595, 2000.

[13] S. Mazza, J-L. Pepin, B. Naegele, J. Plante, C. Deschaux, and P. Levy, "Most obstructive sleep apnoea patients exhibit vigilance and attention deficits on an extended battery of tests," *European Respiratory Journal*, vol. 25, pp. 75-80, 2005.

[14] L. J. Findley, M. J. Fabrizio, H. Knight, B. B. Norcross, A. J. Laforte, and P. M. Suratt, "Driving simulator performance in patients with sleep apnea," *American Review of Respiratory Disease*, vol. 140, pp. 529-530, 1989.

[15] L. J. Findley, M. Unverzagt, R. Guchu, M. Fabrizio, J. Buckner, and P. Suratt, "Vigilance and automobile accidents in patients with sleep apnea or narcolepsy," *Chest*, vol. 108, pp. 619-624, 1995.

[16] C. F. P. George, P. Nickerson, P. Hanley, T. Millar, and M. Kryger, "Sleep apnea patients have more automobile accidents," *Lancet*, vol. 2, pp. A447, 1987.

[17] W. Cassel, T. Ploch, C. Becker, D. Dugnus, J. H. Peter, and P. von Wichert, "Risk of traffic accidents in patients with sleep disordered breathing: reduction with nasal CPAP," *European Respiratory Journal*, vol. 9, pp. 2606-2611, 1996.

[18] H. Yamamoto, T. Akashiba, N. Kosaka, D. Ito, and T. Horie, "Longterm effects of nasal continuous positive airway pressure on daytime sleepiness, mood and traffic accidents in patients with obstructive sleep apnoea," *Respiratory Medicine*, vol. 94, pp. 87-90, 2000.

[19] C. E. Sullivan, F. G. Issa, N. Berthon-Jones, et al., "Reversal of obstructive sleep apnoea by continuous positive airway pressure applied through the nars," *Lancet*, vol. 1, pp. 862-865, 1981.

[20] L. Findley and P. M. Suratt, "Serious motor vehicle crashes: the cost of untreated sleep apnea," *Thorax*, vol. 56, p. 505, 2001.

[21] C. F. P. George, "Motor vehicle collisions are reduced when sleep apnoea is treated with nasal CPAP," *Thorax*, vol. 56, pp. 508-512, 2001.

[22] H. M. Engleman and M. R. Wild, "Improving CPAP use by patients with the sleep apnoea/hypopnea syndrome (SAHS)," *Sleep Medicine Review*, vol. 7, pp. 81-99, 2003.

[23] P. Zimmermann, and B. Fimm, *Test for Attentional Performance (TAP)*. Herzogenrath: Psytest, 1997.

[24] P. Zimmermann and B. Fimm, A test battery for attentional performance. In: M. Leclercq & P. Zimmermann (eds.). *Applied Neuropsychology of Attention. Theory, Diagnosis and Rehabilitation*. Pp. 110-151, 2002.

[25] M. I. Posner and S. E. Petersen, "The attention system of the human brain," *Annual Review of Neuroscience*, vol. 13, pp. 25-42, 1990.