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Sleep stability and transitions in patients with idiopathic REM sleep behavior disorder and patients with Parkinson's disease

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ABSTRACT

Objective: Patients with idiopathic rapid eye movement (REM) sleep behavior disorder (iRBD) are at high risk of developing Parkinson's disease (PD). As wake/sleep-regulation is thought to involve neurons located in the brainstem and hypothalamic areas, we hypothesize that the neurodegeneration in iRBD/PD is likely to affect wake/sleep and REM/non-REM (NREM) sleep transitions.

Methods: We determined the frequency of wake/sleep and REM/NREM sleep transitions and the stability of wake (W), REM and NREM sleep as measured by polysomnography (PSG) in 27 patients with PD, 23 patients with iRBD, 25 patients with periodic leg movement disorder (PLMD) and 23 controls. Measures were computed based on manual scorings and data-driven labeled sleep staging.

Results: Patients with PD showed significantly lower REM stability than controls and patients with PLMD. Patients with iRBD had significantly lower REM stability compared with controls. Patients with PD and RBD showed significantly lower NREM stability and significantly more REM/NREM transitions than controls.

Conclusions: We conclude that W, NREM and REM stability and transitions are progressively affected in iRBD and PD, probably reflecting the successive involvement of brain stem areas from early on in the disease.

Significance: Sleep stability and transitions determined by a data-driven approach could support the evaluation of iRBD and PD patients.

1. Introduction

Parkinson’s disease (PD) and other synucleinopathies are debilitating diseases with impacts on morbidity, mortality, work, and social and family life. The disorders have large direct and indirect costs for society (Jennum et al., 2011). PD is the second most common neurodegenerative disease after Alzheimer’s disease. Treatment is purely symptomatic and does not alter underlying disease progression (Schapira et al., 2013). When motor symptoms are present, alterations of the substantia nigra with reduced production or depletion of dopamine is found (Galvin et al., 2001).
mediating the classical PD phenotype. Over the last 20 years, it has become increasingly clear that the entire brain is affected by the pathology, which typically starts in caudal areas of the brainstem and progresses anteriorly (Braak et al., 2003).

Recent research has focused on early detection of PD, notably changes in sleep–wake pattern and rapid eye movement (REM) sleep without atonia (RSWA) coinciding with dream-enacting behavior – REM sleep behavior disorder (RBD) (Salawu et al., 2010). RBD is closely associated with PD (Munhoz and Teive, 2014), and patients suffering from idiopathic RBD (iRBD) are at great risk of subsequently developing Parkinsonism or dementia (Schenck et al., 2013, 2003, 1996). Several studies have focused on analysis of sleep data in the search for PD biomarkers (Dos Santos et al., 2014). These have examined measures of sleep spindle densities, RSWA, slow wave characteristics (Christensen et al., 2014b; Kempfner et al., 2014a,b; Latreille et al., 2014, 2011; Postuma et al., 2010) and other measures of abnormalities of brain stem function, including autonomic functions such as heart-rate variability (Sorensen et al., 2013a, 2012) and other non-motor symptoms (Garcia-Ruiz et al., 2014; Sakakibara et al., 2014).

Sleep is strongly regulated by groups of neurons located in the brainstem and midbrain areas, which form reciprocal connections (Luppi et al., 2011; Saper et al., 2010, 2001; Schwartz and Roth, 2008). These “sleep–wake switches” are mutually dependent and have been referred to as the wake–sleep and REM–NREM sleep switches, respectively. Despite the mutually inhibitory loops involved in the two switching mechanisms, if either side of the two loops is weakened or injured, unwanted instability can occur in either of the states, irrespective of which side is damaged (Schwartz and Roth, 2008). As neurons of the brain stem and basal brain structures are affected in synucleinopathies (Braak et al., 2003), we propose that the neurodegeneration will have a progressive impact on the wake–sleep and REM–NREM transitions and stability. Manual scoring of sleep in patients with PD is not very reliable and prone to high inter- and intra-rater variability (Danker-Hopfe et al., 2004; Jensen et al., 2010). Therefore, this study analyzed wake–sleep and REM–NREM transitions as well as W, REM and NREM stability measures based on automatically identified as well as manually scored REM, NREM and W stages. The automatic method used has been validated by (Koch et al., 2014) using the same PSG data as analyzed in this study.

2. Methods

2.1. Subjects and recordings

Subjects were recruited from the Danish Center for Sleep Medicine (DCSM) in the Department of Clinical Neurophysiology, Glostrup University Hospital in Denmark. A total of 27 patients with PD, 23 patients with iRBD, 25 patients with periodic leg movement disorder (PLMD) and 23 control subjects aged 40 years or more and with no history of movement disorder, dream-enacting behavior or other previously diagnosed sleep disorders were included. Nineteen of the patients with PD had RBD (PD+) and eight did not (PD−), as determined by the presence of RSWA as well as clinical complaints. All or a subset of the subjects included here have appeared in previous studies (Christensen et al., 2014a,b; Sorensen et al., 2013a; Zoetmulder et al., 2014a,b). Patient evaluations included a comprehensive medical and medication history and a polysomnography (PSG) analyzed according to the American Academy of Sleep Medicine (AASM) standard (Iber et al., 2007). A multiple sleep latency test (MSLT) was performed in any cases where narcolepsy was suspected. The PD diagnose rely on clinical features including motor information typically for PD which further includes DAT scan and in some cases also MRI of the brain. The RBD Screening Questionnaire (RBDSQ) (Stiasny-Kolster et al., 2007) was used to screen for RBD, and the iRBD patients were divided in two groups: (1) those with a total score of nine or less (iRBD−) and (2) those with a total score of 10 or more (iRBD+). The cutoff was chosen to divide the iRBD patients into those with major self-reported dream enactments and those with minor. All iRBD patients thus had self-reported dream enactment as well as RSWA in the recorded night analyzed. Patients treated with medication known to affect sleep stages (antidepressants, antipsychotics, hypnotics) were excluded, except for dopaminergic treatments. We are fully aware of the potential effect of dopaminergic drugs on vigilance (Micallef et al., 2009), but discontinuation of dopaminergic treatment in actively treated patients prior to PSG also risks deleterious discontinuation effects. Furthermore, discontinuation is very difficult to achieve in clinical settings and may have unpleasant and negative motor effects that could interfere with the study and might even be unethical. One patient in the PD group later developed Multiple System Atrophy and another patient with PD developed Lewy Body Dementia. Controls underwent at least one night of PSG as an outpatient. Patients underwent at least one night of PSG as an outpatient or in hospital in accordance with the AASM standard (Iber et al., 2007). The quality of each PSG data set was individually evaluated, and recordings were discounted if channels became disconnected or were significantly contaminated with artifacts. Low-quality PSGs were repeated whenever possible. Demographic data as well as PSG variables for the six groups are summarized in Table 1.

2.2. Automatic staging of sleep

Sleep changes in both microarchitecture and macroarchitecture have been reported in neurodegenerative disease, the former interfering with sleep scoring and increasing intra- and inter-rater variability. Specifically, patients with iRBD and PD have been reported to have EEG frequency slowing (Rodrigues Brazète et al., 2013), changed EEG during REM sleep (Christensen et al., 2014a; Fantini et al., 2003; Hansen et al., 2013), changed morphology or fewer rapid or slow eye movements (Christensen et al., 2014a, 2013) and sleep spindles (SS) (Christensen et al., 2014b; Latreille et al., 2014), and display RSWA. The listed findings contribute to very altered sleep and consequently, sleep stage scoring this pathology is associated with high inter-rater variability (Danker-Hopfe et al., 2004; Jensen et al., 2010). To overcome this, an automatic sleep detector was used to identify REM, NREM and W for each subject and analyses were performed using automatically scored sleep data. The automatic sleep scoring technique used in this study has been validated on the same PD, iRBD, PLMD and control PSG data set as used in this study, and the methods are described in detail by Koch et al. (2014). Specifically, the method is optimized on nocturnal PSG of 50 subjects, and validated on an additional 76 subjects (a mixture of the same controls and patients included in this study). Our automatic detector is data-driven, identifying sleep states based on the distribution of certain EEG and electrooculographic (EOG) characteristics, which can be interpreted as specific fingerprints for each epoch. Due to the presence of RSWA, the automatic identification approach is based on EEG and EOG characteristics only. Briefly, for each second, EEG C3-A2 and O1-A2 single-sided amplitude spectra in clinical frequency bands as well as EOG power below 5 Hz and cross-correlations between the two EOG channels are computed. Surveying these measures simultaneously in three-second intervals with a step size of one second, the approach identifies patterns indicative of the various sleep stages. The method produces a mixture of probabilities for the different sleep stages, and final identification of NREM, REM and W is based on the highest probability when combining probabilities of individual sleep stages (Koch et al., 2014). A clear
Table 1
Demographic and PSG data for the six groups studied. Patients with Parkinson’s disease (PD) were divided in those with REM sleep behavior disorder (RBD) (PD+) and those without (PD−), as determined by the presence of REM sleep without atonia as well as clinical complaints. The RBD Screening Questionnaire was used to divide the patients with idiopathic RBD (iRBD) in those with a total score of <9 (iRBD−) and those with a score of ≥9 (iRBD+). Patients with periodic leg movement disorder (PLMD) were included as a secondary control group. The disease onset is stated as years from clinical diagnosis (PD patients) or self-reported subjective RBD-symptoms (iRBD patients).

<table>
<thead>
<tr>
<th></th>
<th>Controls</th>
<th>PLMD</th>
<th>iRBD−</th>
<th>iRBD+</th>
<th>PD</th>
<th>PD−</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total counts (Male/Female)</td>
<td>23 (7/16)</td>
<td>25 (13/12)</td>
<td>12 (9/3)</td>
<td>11 (10/1)</td>
<td>8 (5/3)</td>
<td>19 (13/6)</td>
</tr>
<tr>
<td>Age [years, μ ± σ]</td>
<td>56.7 ± 9.2</td>
<td>56.9 ± 11.6</td>
<td>61.8 ± 6.8</td>
<td>66.3 ± 7.2</td>
<td>68.8 ± 8.4</td>
<td>63.7 ± 6.7</td>
</tr>
<tr>
<td>BMI [kg/m², μ ± σ]</td>
<td>23.1 ± 2.5</td>
<td>25.7 ± 3.8</td>
<td>25.1 ± 2.6</td>
<td>25.9 ± 3.6</td>
<td>24.1 ± 3.6</td>
<td>25.9 ± 2.9</td>
</tr>
<tr>
<td>Sleep Efficiency [%, μ ± σ]</td>
<td>86.2 ± 10.9</td>
<td>86.1 ± 7.5</td>
<td>82.5 ± 7.4</td>
<td>85.8 ± 6.7</td>
<td>67.9 ± 15.5</td>
<td>80.3 ± 9.9</td>
</tr>
<tr>
<td>Time in Bed [min, μ ± σ]</td>
<td>484 ± 81.2</td>
<td>431 ± 50.0</td>
<td>518 ± 107.3</td>
<td>474 ± 71.1</td>
<td>427 ± 53.8</td>
<td>461 ± 88.3</td>
</tr>
<tr>
<td>W [%, μ ± σ]</td>
<td>13.8 ± 10.9</td>
<td>13.9 ± 7.5</td>
<td>17.5 ± 7.4</td>
<td>14.2 ± 6.7</td>
<td>32.1 ± 15.5</td>
<td>19.7 ± 9.9</td>
</tr>
<tr>
<td>REM [%, μ ± σ]</td>
<td>18.9 ± 6.6</td>
<td>18.5 ± 6.1</td>
<td>17.7 ± 7.1</td>
<td>16.3 ± 7.1</td>
<td>9.3 ± 5.3</td>
<td>14.6 ± 10.8</td>
</tr>
<tr>
<td>N1 [%, μ ± σ]</td>
<td>8.8 ± 4.6</td>
<td>8.4 ± 7.2</td>
<td>7.5 ± 2.6</td>
<td>10.8 ± 5.4</td>
<td>7.3 ± 6.0</td>
<td>12.6 ± 9.9</td>
</tr>
<tr>
<td>N2 [%, μ ± σ]</td>
<td>44.7 ± 9.4</td>
<td>44.7 ± 10.9</td>
<td>40.0 ± 10.9</td>
<td>43.0 ± 10.3</td>
<td>39.2 ± 12.9</td>
<td>39.3 ± 15.1</td>
</tr>
<tr>
<td>N3 [%, μ ± σ]</td>
<td>13.8 ± 7.3</td>
<td>14.5 ± 9.1</td>
<td>17.3 ± 9.9</td>
<td>15.7 ± 11.2</td>
<td>12.1 ± 9.1</td>
<td>13.9 ± 17.6</td>
</tr>
<tr>
<td>LM index [no/hour, μ ± σ]</td>
<td>18.1 ± 13.1</td>
<td>56.5 ± 36.8</td>
<td>49.9 ± 32.0</td>
<td>31.6 ± 22.9</td>
<td>39.2 ± 40.1</td>
<td>42.7 ± 44.4</td>
</tr>
<tr>
<td>PLM index [no/hour, μ ± σ]</td>
<td>7.7 ± 7.4</td>
<td>36.5 ± 24.6</td>
<td>14.9 ± 16.3</td>
<td>23.0 ± 17.1</td>
<td>11.2 ± 11.5</td>
<td>10.8 ± 10.3</td>
</tr>
<tr>
<td>Disease duration [years, μ ± σ]</td>
<td>NA</td>
<td>NA</td>
<td>5.3 ± 9.8</td>
<td>11.3 ± 12.0</td>
<td>7.7 ± 5.7</td>
<td>4.6 ± 3.3</td>
</tr>
<tr>
<td>RBD score [μ ± σ]</td>
<td>NA</td>
<td>NA</td>
<td>7.7 ± 1.6</td>
<td>11.1 ± 1.0</td>
<td>2.5 ± 1.1</td>
<td>9.7 ± 2.3</td>
</tr>
</tbody>
</table>

3. Results

Transition and stability measures computed from the automatically identified NREM, REM and W are illustrated in Fig. 1, and the results found from the manually scored hypnogram are illustrated in Fig. 2. Mean and standard deviations are illustrated in bar plots to the left and measures for each subject illustrated as dots to the right.

The results obtained from the automatically identified stages showed that patients with iRBD with a RBDSQ total score of nine or lower had significantly lower REM stability compared with controls (p = 0.0106). Patients with iRBD with a RBDSQ total score of ten or more had significantly lower REM stability compared with controls (p = 0.0036) and PLMD patients (p = 0.0091). PD patients without RBD showed significantly lower REM stability compared to the controls (p < 0.0055) and PLMD (p < 0.0052). PD patients with RBD had significantly lower REM stability than controls (p = 0.0003) and PLMD patients (p = 0.0004), significantly lower NREM stability than controls (p = 0.0050), and significantly more REM–NREM sleep transitions than controls (p = 0.0107). Finally, iRBD patients with a RBDSQ total score of nine or lower showed a trend towards lower REM stability compared with PLMD patients, and iRBD patients with a RBDSQ total score of ten or more showed a trend of more REM–NREM sleep transitions than controls. However, these trends were not statistically significant after correction for multiple testing. No significant differences were found between any of the iRBD and PD groups, although PD patients showed a trend towards lower REM stability and more REM–NREM sleep transitions compared with iRBD patients.

No significant between-group differences were found for the transition and stability measures computed from the manually scored hypnograms. It is seen that the stability measures computed from the manually scored hypnogram are all greater than the measures computed from the data–driven sleep staging technique. The measures for REM–NREM sleep transitions are greater for the automatic staging technique compared to the manually.
scored sleep stages, and the differences between the REM stability measures are thought to be the main cause hereof.

4. Discussion

This study is the first to analyze wake–sleep and REM–NREM transitions and the stability of REM, NREM and W in PD, iRBD and PLMD patients compared with controls. Furthermore, we divided the PD patients into those with and those without RBD, and the iRBD patients were divided in those with a high total score on the RBDSQ and those with a low score. Our main findings are: (1) REM sleep is less stable in iRBD and PD patients than in PLMD patients and control subjects, regardless of the RBDSQ total score and the presence of RBD. A non-significant trend was seen for a lower REM sleep stability in PD compared to iRBD patients. (2) PD patients with RBD showed significantly lower NREM stability and significantly more REM–NREM shifts than controls. Same trend, however non-significant, was seen for iRBD with high scores in the RBDSQ compared with control subjects. Overall, trends were seen for lower REM stability and more REM/NREM transitions in both groups of iRBD and PD patients. These results indicate that the ability to maintain REM and NREM sleep is a biomarker for iRBD and PD, regardless of the presence of clinical symptoms.

The sub-division of iRBD and PD patients might not be optimal, as it does not reflect the actual RBD severity in the recording analyzed. The PD patients without RBD might have RSWA to a certain degree but no RBD diagnosis as they lack to report subjective symptoms. Contradictory, the iRBD patients with major self-reported dream enactments might show just sufficient RSWA to be diagnosed. Analyzing trends for the stability and transitional measures as a function of clinical RBD severity could give a better insight in how correlated the features are with RBD severity. The clinical RBD severity scale reported in (Sixel-Döring et al., 2011) analyzes RBD on an event-to-event basis, including both vocalization and movements, and could be used in future studies to look for such trends and correlations.

Wake–sleep and REM–NREM shifts as well as stability measures were computed based on the manually scored hypnogram as well as a data-driven identification of REM, NREM and W stages. A data-driven model recognizes the underlying structure of the data and automatically identifies wake and sleep stages. Using a data-driven sleep staging approach has several advantages over manual scoring.
First, automatic staging encompasses micro-sleep characteristics delineated over time intervals as short as one second; the dynamics over such short intervals are not captured by manual scoring, which is of a much lower resolution. The model looks deeper into each sleep epoch and can survey and identify many more sleep characteristics than the human eye can assess. Although final identification is made for 30-s intervals in the automatic detection as well, decisions are based on changes or transitions occurring at a much faster rate.

Second, using an automatic, data-driven approach, sleep stages across the night as well as across subjects are more comparable as they are obtained using exactly the same algorithm. Third, using the automatic model, identification of each epoch is based solely on micro-sleep characteristics and changes within the epoch in question, rather than on the scoring of adjacent epochs. As the model features the analysis of short time intervals, it enables a highly detailed description of each sleep epoch, which reduces variation in inter- and intra-subject scoring. Consistent with this, manual scorings for patients with PD have low inter-rater agreement rates (Danker-Hopfe et al., 2004; Jensen et al., 2010).

No significant differences between groups were found for the manually scored hypnograms, whereas the data-driven labeling indicated many between-group differences. The reason for these contradictory results are suggested to be caused by the two different sleep scorings strategies. The fact that the data-driven method makes the labeling solely based on the characteristics of the epoch in question and not the labeling of the prior epoch allows in specific REM sleep to be terminated when no clear EEG and EOG structures supporting REM sleep are present. Contrarily, manually scorings terminate REM sleep only when a clear NREM or W structure is present (Iber et al., 2007). Specifically, REM sleep is besides the characteristic eye movements identified by atonia and EEG similar to that during wakefulness. In periods where eye movements are not present, but the atonia as well as the aroused EEG is maintained, the manual scoring of REM sleep is continued. Relating this to EMG with lack of atonia and EEG with altered characteristics or lack of clear micro-sleep structures as seen in patients with PD or iRBD (Christensen et al., 2014a,b; Dauvilliers et al., 2007; Fantini et al., 2003; Kempfner et al., 2014a,b; Petit et al., 2004), termination of REM sleep is harder to confirm for a manual scorer. As a result, the manually scorings lack to illustrate differences in the REM stability measure, as well as in the REM–NREM sleep transitions.

Fig. 2. The frequencies of wake–sleep and REM–NREM shifts and the stability measures for REM sleep, NREM sleep and wake for the six groups based on the manually scored REM, NREM and W epochs. Left, bar charts with heights indicating means, and error bars indicating one standard deviation of the observations above and below the mean. Right, results from each subject indicated as dots. Dark blue, control subjects; light blue, PLMD patients; light red, iRBD patients; dark red, patients with Parkinson’s disease (PD). Asterisks indicate a significant between-group difference, determined by Wilcoxon rank-sum tests: *p < 0.05; **p < 0.01; ***p < 0.001. The Benjamini–Hochberg procedure was used to control the false discovery rate (FDR) at level q = 0.10. Fifteen between-group comparisons were made of five measures, giving a total of 75 tests. No comparisons remained significant after FDR correction. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
The sleep regulating mechanisms involve several neurons, which are mainly located in the basal brain regions (Luppi et al., 2011; Saper et al., 2001). Our findings suggest that these mechanisms are affected in patients with iRBD and specifically in patients with PD, suggesting iRBD as an intermediate stage between controls and patients with PD, consistent with Braak's staging theory (Braak et al., 2003). Specifically, REM stability was affected, which involves the neurological networks controlling REM–NREM sleep transitions presented as consisting of REM-on and REM-off areas located in the brainstem (Lu et al., 2006; Luppi et al., 2011). The REM-on area is thought to contain two populations of neurons, where one set projects into the basal forebrain and regulates EEG components of REM sleep, and the other projects into the medulla and spinal cord and regulates atonia during REM sleep (Lu et al., 2006). As a diagnostic criterion of RBD is loss of atonia during REM sleep, the neurons regulating atonia must be affected to some degree in these patients. The REM staging and thereby the REM stability measures in this study were only based on EEG and EOG characteristics, suggesting that the neurons regulating the cortical components of REM sleep are also affected, agreeing with previous findings (Fantini et al., 2003). Specifically, it is proposed that the REM-specific EEG structures are signified to a lesser degree in iRBD and PD patients than in controls and PLMD patients. The reason for this could be neurodegeneration of the ascending branch of the SLD neurons themselves or the heavy innervation between the son for this could be neurodegeneration of the ascending branch of iRBD and PD patients than in controls and PLMD patients. The rea-

5. Conclusions

In conclusion, our study suggests that patients with iRBD and PD suffer from instability in the wake–sleep and NREM–REM transitions and instability of wake and sleep. These findings are in accordance with the initial hypothesis that iRBD is an early form of PD and that the basal brain is involved in these diseases in early disease stages. Our results further argue for the problems that these patients suffer from micro-sleep and nocturnal sleep fragmenta

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References
