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Research Article

Impaired Sleep and Reduced Spontaneous Movement Activity in Acute Stroke: An Exploratory Study

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Abstract

Background and Purpose:

To explore the relation of spontaneous arm movement activity to the EEG patterns in the acute phase after stroke.

Methods:

Included into this prospective study were 9 stroke patients (68.2±7.6 years; 3 females, 6 males) and 9 age-matched controls (68.2±11.7 years; 2 females, 7 males). 24-hour video EEG was performed approximately 10 days after stroke. Movement activity was measured continuously and synchronously with the EEG for 24 hours in both arms using actiwatches.

Results:

Compared to controls, the stroke patients had lower total sleep time (P=0.031), sleep efficiency (P=0.019), %NREM (P=0.034) and %sleep stage N2 (P=0.003). The stroke group showed a loss of correlation of spontaneous movement activity among their arms due to reduced spontaneous movement activity in the affected arm during wakefulness. Stroke patients with abnormal focal slow wave activity (SWA) showed less spontaneous arm movement activity than those without SWA, while there were no differences in sleep parameters.

Conclusion:

Our exploratory study supports the notion that stroke patients suffer changes of sleep parameters and abnormal EEG patterns which are related to reduce spontaneous arm movement activity.

Keywords: Stroke; Electroencephalogram; Actiwatch; Focal Slow Wave Activity

Introduction

Stroke damages the brain and most frequently becomes apparent clinically by hemiparesis. Recordings with the electroencephalogram (EEG) have revealed that stroke patients may exhibit focal slow waves activity (SWA) of 1 to 4 Hz as well as focal epileptic changes in the affected hemisphere [1-3]. Focal SWA (1-4 Hz) has been reported to predict poor recovery from stroke [1-6] but can last even for years as was described in aphasic stroke patients [7]. Notably, EEG recordings have revealed that, in addition to their neurological deficit, stroke patients also have abnormal sleep architecture [8,9]. It is unclear, however, what the functional impact of SWA is on spontaneous movement activity of the affected side after stroke. In fact, stroke patients with similar infarcts concerning lesion location and volume may show recovery patterns of the formal neurological assessment that are not reflected by the spontaneous movement activity of the affected limbs [10,11].

Accelerometry with actiwatches is a well-established and validated method for recording spontaneous movement activity of arms or legs [11-13]. Thereby, one can detect an impairment of spontaneous movement activity even if such an abnormality cannot be found during the formal neurological examination [12,13]. Since there is the notion that EEG patterns may be related to the clinical recovery of stroke [14-18], we used actiwatches in this study to study the hypothesis that the abnormality of spontaneous arm movements in stroke patients may be related to abnormal EEG patterns. Here, we present initial observations showing that focal EEG abnormalities were related to a lack of spontaneous movement activity in patients with cortical stroke as evident from simultaneous actigraph recordings.

Methods

Stroke patients

This prospective clinical study was performed from March 2013 until April 2014. Included into the study were 9 consecutive, right-handed patients who were treated in the Centre of Neurology and Neuropsychiatry of the LVR Klinikum Düsseldorf, aged 68.2±7.6 years presenting with acute ischaemic stroke.

Inclusion criteria were:

1. Onset of hemipares is no more than 14 days before the 24-hour video EEG recording,

2. Acute ischaemic infarct lesion assessed by diffusion weighted magnetic resonance imaging (MRI),

3. First-ever stroke with no prior brain lesions as detected by T2 weighted MRI,

4. Full capacity to comply with the task instruction.

Exclusion criteria were:

1. Severe systemic disease such as sepsis, myocardial infarct, etc. and past epilepsy or seizures,

2. Reduced consciousness,

3. Intracranial hemorrhage,

4. Sensory aphasia,

5. Anticonvulsive or sedative treatment.

During their stay in hospital, the patients received medical treatment with respect to their specific status according to the present stroke guideline [19]. One stroke patient received systemic thrombolysis treatment with body-weight adjusted alteplase. All patients had a continuous monitoring of heart rate, blood pressure, blood oxygen saturation, measurement of body temperature, and testing of blood samples including blood sugar levels of at least 72-hour duration. The score of the National Institutes of Health Stroke scale (NIHSS) [20] was assessed by experienced clinical observers on admission, at six hour intervals during the first 72 hours, and at discharge.

The 24-hour video-EEGs and concurrent actigraph recordings were performed at the time when the patients could be transferred out from the acute stroke unit to the video-EEG examination room. Informed consent was obtained from each patient before the investigation. The study was approved by the Ethics Committee of the Heinrich-Heine University, Düsseldorf (#4206).

Controls

Nine age- and gender-matched, right-handed subjects (two women, seven men) aged 68.2±11.7 years served as controls. They had a 24-hour video-EEG and actiwatch recordings identical to those of the stroke patients (see below). They were hospitalized in our department between March 2013 and April 2014 because of suspected epileptic seizures, but were neurologically normal, had no focal brain lesion on MRI and a normal EEG even after sleep deprivation.

Accelerometry

To invest the spontaneous movement activity of both arms continuously, recordings with actiwatches (Cambridge

Neuro-technology, Cambridge, UK; http://camntech.co.uk) were done. The device, a small light-weight gadget the size of wrist-watch, synchronously recorded arm movements for 24h in all three dimensions with movement-sensitive sensors. We set the sampling of actiwatch recordings at one minute. Activity was binned into minutes in which the movement activity was integrated by each device (Actiwatch Activity &Sleep Analysis 5.42, Cambridge Neuro-technology). Before the recording started, the actiwatches were calibrated that they assessed the same movement scene and to apply a linear regression to normalize the sensitivity of the actiwatches.

Data were analyzed off-line using SPSS (version17.0;SPSS Inc.) software. The movement artifacts due to nursing were eliminated from the data. To assess asymmetries of arm movement activity, the activity patterns of the two arms were correlated using the Spearman rank correlation (rs). The relative arm movement activity (RMA) was the mean activity of the affected arm divided by that of the unaffected arm in the stroke patients, and the mean activity of the left arm divided by that of the right arm in the controls.

Video-EEG recording

EEGs were recorded using a nineteen-channel analogue recorder (Nihon Kohden EEG-1200) according to the international 10–20 system [21] continuously for 24 hours. In addition, a video camera (Nihon Kohden) located on the ceiling above the patient recorded the behavioral data. EEG and video data were recorded in a time-locked fashion. The electrodes were placed using a quantified ruler and a marker pencil to mark strictly on the scalp by hand. The impedances of the electrodes were kept less than 10 kΩ. Filter settings were 0.3–40 Hz. Also, to score sleep stage accurately, we placed electrooculographic channels following the Manual of the American Association of Sleep Medicine (AASM) for the Scoring of Sleep and Associated Events: rules, terminology and technical specifications [22]. The EEG and video data were displayed simultaneously off-line on a personal computer for formal and statistical analysis. Two reviewers scored the sleep stages mainly based on AASM Manual. Reference montages (reference electrodes: Cz, average electrode) were used as well as bipolar montages (longitudinal: Fp2-F4, F4-C4, C4-P4, P4-O2; Fp2-F8, F8-T8, T8-P8, P8-O2 (accordingly on the left side) to assess sleep stages and epileptiform discharges and focal SWAs. According to the AASM Manual, sleep was classified as rapid eye movement sleep (REM), non-REM sleep including the sleep stages N1, N2, and N3. Abnormal focal SWA was defined as [5, 23]: 1) slow wave activities (1-4Hz) presented asymmetrically in EEG electrodes during non-deep sleep stage. 2) SWA episodes were shown ≥75% in 30-second-epoches recurrently. When the two reviewers reached an agreement the data would be brought into the finally statistical analysis.

Statistical evaluation

Clinical and score data and the kinematic recordings using the actiwatches were analyzed using descriptive statistics. The data were presented in the form of mean± standard deviation (SD). The movement relationship of the two arms was characterized by the Spearman's rank correlation coefficient (rs). Group comparisons of the quantified items were based on two-tailed t-test. The qualitative variables were compared using the Mann-Whitney test. Only differences with P values smaller than 0.05 were considered significant. The regression equation of the movement activity of the two arms was determined by linear regression analysis.

Results

The demographic and clinical characteristics of the stroke patients and controls are summarized in Table 1.

Table 1: Demographics, electroencephalogram, and actiwatch parameters

	Stroke group (n=9)	Control group (n=9)	*P*
Male : female(ratio)	6:3	7:2	0.730
Age (years, mean±SD)	68.2±7.6	68.2±11.7	0.863
Actiwatch parameters			
r_s in daytime (mean±SD)	0.462±0.249	0.752±0.127	0.019
r_s in night awake time (mean±SD)	0.549±0.235	0.802±0.129	0.050
r_s in night sleep time(mean±SD)	0.405±0.244	0.585±0.215	0.161
RMA in daytime (%, mean±SD)	38.0±30.5	104.6±45.1	0.004
RMA in night awake time (%, mean±SD)	40.6±37.5	105.6±36.4	0.004
RMA in night sleep time (%, mean±SD)	52.9±47.5	100.3±42.4	0.077
Electroencephalographic parameters			
Sleep latency (min, mean±SD)	16.7±7.6	19.0±11.6	0.965
Wakeup after sleep onset (min, mean±SD)	284.7±126.3	131.9±60.9	0.012
Total sleep time (min, mean±SD)	315.7±125.9	419.2±66.7	0.031
REM latency (min, mean±SD)	224.2.3±49.8	134.7±66.1	0.009
Sleep efficiency (%)	55.1±16.9	74.1±9.7	0.019
Sleep architecture			
R (%, mean±SD)	2.2±1.7	4.6±3.8	0.268
N 1 (%, mean±SD)	16.6±12.0	13.7±4.9	0.847
N 2 (%, mean±SD)	20.9±8.1	36.8±8.5	0.003
N 3 (%, mean±SD)	15.7±9.5	19.0±11.7	0.700
NREM (%, mean±SD)	53.3±16.3	69.5±16.1	0.034

Legend: r_s = Spearman rank correlation of spontaneous movement activity of right and left hand. RMA: relative movement activity of the affected as compared to the non-affected arm in stroke patients and left to right arm in controls. Sleep stages R, N1, N2, N3, NREM: non rapid eye movement sleep, REM: rapid eye movement sleep according to the AASM Manual [22]..

The sex ratios and ages of the two groups showed no differences. The actiwatch data revealed that arm movement activity was poorly correlated in the stroke patients in contrast to the control subjects. Compared to controls, the stroke patients showed a reduced relation of movement activity of their two

arms during daytime (rs =0.462, P=0.019) and night awake time (rs =0.549, P=0.050). This was due to a lower RMA of the affected relative to the non-affected arm at daytime (P=0.004) and night awake time (P=0.004) when compared to RMA of the left to right arm in the controls. Note that the differences of rs and RMA did not exist during night sleep time (Table 1). The EEG recordings revealed that there were significant decreases in total sleep time (TST, P=0.031), sleep efficiency (SE, P=0.019), and wake time after sleep onset (WASO, P=0.012), and an increased REM latency (P=0.009) in the stroke patients (Table 1). Concerning the sleep architecture the mean percentage of sleep stage N2 was reduced in the stroke patients (P=0.003).

To further analyze the relationship between spontaneous arm movement activity and the EEG pattern, we divided the nine stroke patients into two groups: patients with SWAs (n=4) and patients without SWAs (n=5). The results showed that the two groups were comparable concerning sex ratio, age, interval since stroke onset and NIHSS at admission (Table 2).

Table 2: Stroke patients with and without Slow Wave Activity (SWA)

	SWA subgroup (n=4)	No SWA subgroup (n=5)	*P*
Male : female(ratio)	2:2	4:1	0.655
Age (years, mean±SD)	64.7±5.0	68.2±8.1	0.453
Time since stroke (days, mean±SD)	12.0±1.7	8.8±5.1	0.442
Cortical:subcortical stroke (ratio)	3:1	1:4	0.120
NIHSS on admission (mean±SD)	10.3±6.4	6.2±4.4	0.387
NIHSS at discharge (mean±SD)	10.7±2.5	1.8±2.0	0.014
NIHSS changes(mean±SD)	0.3±4.0	-4.4±4.5	0.080
Actiwatch parameters			
r_s in daytime (mean±SD)	0.266±0.152	0.618±0.195	0.050
r_s in night awake time (mean±SD)	0.368±0.141	0.693±0.192	0.027
r_s in night sleep time (mean±SD)	0.251±0.183	0.528±0.228	0.086
RMA in daytime (%, mean±SD)	8.6±8.2	61.6±16.0	0.014
RMA in night awake time (%, mean±SD)	6.2±3.9	68.1±26.1	0.014
RMA in night sleep time (%, mean±SD)	8.1±8.3	88.7±28.9	0.014
Electroencephalographic parameters			
Wakeup after sleep onset (min, mean±SD)	318.5±94.9	257.7±152.0	0.324
Total sleep time (min, mean±SD)	335.9±139.6	299.6±127.9	0.696
REM latency (min, mean±SD)	218.3±71.3	229.0±33.1	0.771
Sleep efficiency (%)	55.7±16.6	54.7±19.2	0.937
Sleep architecture			
R (%, mean±SD)	2.7±2.2	1.7±1.1	0.734
N 1 (%, mean±SD)	14.4±6.4	19.1±16.8	0.867
N 2 (%, mean±SD)	20.9±8.9	20.8±8.4	0.773
N 3 (%, mean±SD)	19.7±11.0	11.6±6.7	0.386
NREM (%, mean±SD)	55.0±16.7	51.6±18.3	0.950

Legend: r_s = Spearman rank correlation of spontaneous movement activity of right and left hand.
RMA: relative movement activity of the affected as compared to the non-affected arm in stroke patients and left to right arm in controls. Sleep stages R, N1, N2, N3, NREM: non rapid eye movement sleep, REM: rapid eye movement sleep according to the AASM Manual [22].

But two patients in the SWA subgroup had epileptic discharges, while there was none in the no-SWA patient group. Further, the patients with SWAs had a lower relation of movement activity of the affected relative to the non-affected arm at daytime (P=0.050) and during night wake time (P=0.027). This was due to a more reduced RMA in the patients with SWAs as compared to those without SWAs during daytime and during night awake time (P=0.014, respectively). At discharge, the patients with SWA had neurological deficits as severe as on admission, while the patients without SWA had profoundly improved and were less affected as assessed with the NIHSS (P=0.014). The sleep parameters and sleep architecture of the two groups, however, did not differ (Table 2).

We divided the stroke patients into a cortical infarct group and a subcortical infarct group. Of the four stroke patients with cortical lesions one showed SWAs and two both epileptiform discharges and SWAs. Instead, there was only one patient with SWAs and no patient with epileptiform discharge activity in the subcortical infarct group. The cortical infarct patients differed from the subcortical infarct patients by a greater neurological deficit on admission and by less movement activity of the affected arm during night sleep (Supplemental table I).

Supplemental Table: Stroke patients with cortical vs.subcortical infarcts

	Cortical infarcts (n=4)	Subcortical infarcts (n=5)	*P*
Male : female (ratio)	2:2	4:1	0.655
Age (years, mean±SD)	69.3±9.9	65.4±6.1	0.219
Stroke onset time (days, mean±SD)	11.0±3.0	9.4±5.1	0.756
NIHSS on admission (mean±SD)	14.0±1.0	4.0±1.0	0.014
NIHSS at discharge (mean±SD)	8.7±5.9	3.0±3.5	0.108
NIHSS changes (mean±SD)	-5.3±5.8	-1.0±3.7	0.802
Patients with SWAs	3	1	0.120
Patients with epileptic discharges	3	0	0.025
Actiwatch parameters			
r_s in daytime (mean±SD)	0.364±0.315	0.540±0.181	0.327
r_s in night awake time (mean±SD)	0.516±0.279	0.575±0.225	0.462
r_s in night sleep time (mean±SD)	0.387±0.340	0.419±0.179	0.624
RMA in daytime (%, mean±SD)	23.5±27.5	49.4±30.6	0.221
RMA in night awake time (%, mean±SD)	24.2±36.9	53.7±36.2	0.286
RMA in night sleep time (%, mean±SD)	17.1±25.4	81.5±41.4	0.027
Electroencephalographic parameters			
Sleep latency (min, mean±SD)	13.9±7.6	19.0±7.6	0.327
Wakeup after sleep onset (min, mean±SD)	271.0±142.7	295.7±127.6	0.806
Total sleep time (min, mean±SD)	348.2±128.6	289.8±132.0	0.327
REM latency (min, mean±SD)	224.5±68.4	224.0±38.1	1.000
Sleep efficiency (%)	48.9±15.9	60.1±17.8	0.462
Sleep architecture			
R (%, mean±SD)	2.3±1.9	2.1±1.8	0.773
N 1 (%, mean±SD)	11.7±4.9	21.8±15.6	0.284
N 2 (%, mean±SD)	21.0±9.0	20.8±8.4	0.486
N 3 (%, mean±SD)	16.3±9.9	15.0±7.4	0.691
NREM (%, mean±SD)	48.9±13.1	57.6±20.0	0.386

Legend: r_s = Spearman rank correlation of spontaneous movement activity of right and left hand.
RMA: relative movement activity of the affected as compared to the non-affected arm in stroke patients and left to right arm in controls. Sleep stages R, N1, N2, N3, NREM: non rapid eye movement sleep, REM: rapid eye movement sleep according to the AASM Manual [22]..

Three of four cortical infarct patients had similar lesions, but they had different EEG patterns and actiwatch parameters. Patient 1 showed abnormal epileptiform discharges and no SWA (Figure 1). The patient had an ischaemic infarct which affected the right peri-insular cortex but spared the subcortical structures such as the basal ganglia and the internal capsule. On admission she was severely affected (NIHSS 14) and subjected to systemic thrombolysis which improved her neurological condition profoundly (NIHSS of 2 at discharge). She showed a high relative movement activity (63.7% at daytime and 68.0% at night respectively). Her arm movement activity was highly correlated among the two arms rs 0.803 at daytime and 0.855 at night respectively, and with a high symmetry across the two arms as evident from the regression coefficient (Figure 1).

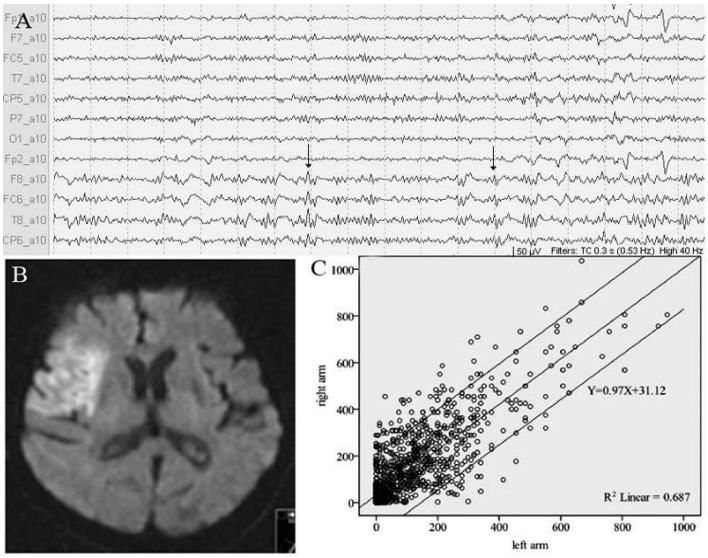

Figure 1: A 78 year-old woman with peri-insular infarct and highly correlated arm movement activity and epileptiform discharges in EEG (arrow).

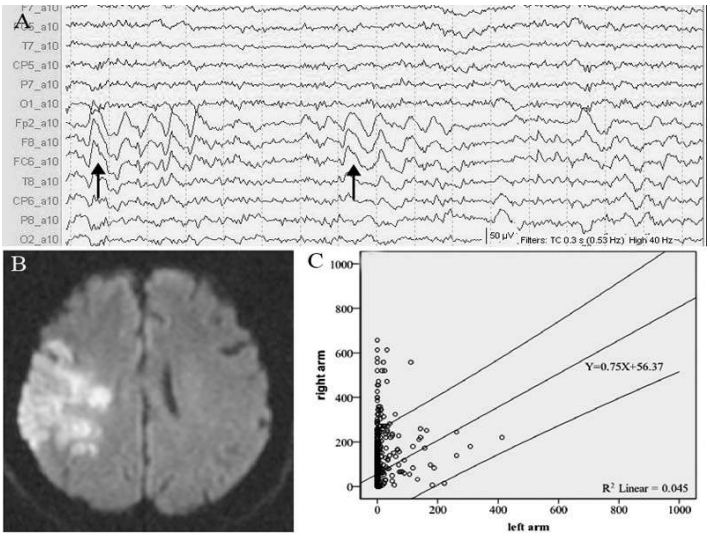

Figure 2: A 60 year-old man with an ischaemic infarct affecting the pericentral and anterior parietal cortex and a severe clinical involvement. Note the lack of correlation of the activity of his two arms. The EEG revealed focal slow wave activity (thick arrows).

Patient 2 suffered an ischaemic infarct affecting the right pericentral and anterior parietal cortex involving also the hemispheric paraventricular white matter (Figure 2). He was severely affected with a NIHSS 13 on admission and 11 at discharge, respectively. The patient showed focal SWA but no epileptiform discharges. The actiwatches showed that he had a low relative movement activity of his affected arm (10.0% within 24 h, 10.0% at daytime and 11.0% at night respectively) and a low correlation of the movement activity of his arms (rs of, 0.368 at daytime and 0.522 at night, respectively.

Patient 3 suffered an ischaemic infarct lesion affecting the centre of the territory of the right middle cerebral artery including the insular and temporal cortex as well as the basal ganglia and the entire posterior limb of the internal capsule (Figure 3). His NIHSS was 15 at baseline and 13 at discharge, respectively. The patient showed a very low relative movement activity during daytime (2.1%) and even less at night (0.7%) and generated almost no movement activity with his affected left arm but lots of activity with his right arm. His EEG revealed both abnormal epileptiform discharge and focal SWA (Figure 3).

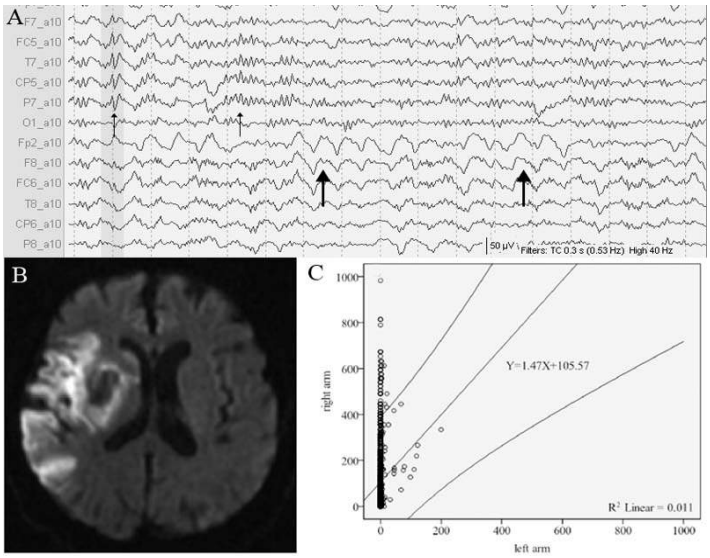

Figure 3 a 70 year-old man with an ischaemic infarct of the insular and temporal cortex, basal ganglia and the entire posterior limb of the internal capsule. The EEG showed SWA in right frontal-temporal leads (thick arrows) and epileptiform discharges in left temporal leads (arrows).

In addition, we noted that one patient with a right-sided subcortical infarct showed focal SWA in the EEG. His ischaemic infarct lesion involved the basal ganglia and the anterior and posterior limb of his internal capsule. The NIHSS was 3 on admission but he deteriorated despite aspirin treatment leaving him with a NIHSS of 8 at discharge. The patient showed a very low RMA (4.5%) with a low correlation of both arms (Figure 4).

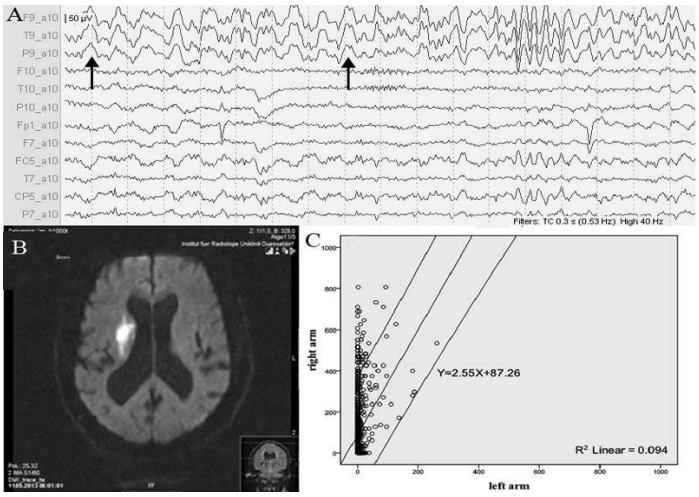

Figure 4: A 64 year-old man with an ischaemic infarct lesion involving the right basal ganglia and the internal capsule. He had very low relative movement activity of his affected arm (4.5%) and left frontal SWA in the EEG (thick arrows).

Discussion

In this study we aimed at assessing the spontaneous movement activity of the affected arm and EEG abnormalities in patients with first ever ischaemic stroke in the early phase after the insult. To this end we combined 24-hour video EEG recordings with the use of actiwatches, which provide ominidirectional accelerometric measurements of limb movements in real time [24,25]. There were two major findings. First, the EEG recordings revealed that the stroke patients had profoundly less sleep time, sleep efficiency, and proportion of sleep stage N2 than the control subjects. These findings accord with earlier observations by Bassetti and colleagues [2] supporting the notion that sleep architecture is impaired in stroke patients leading to sleep fragmentation, increased wakefulness, and increased REM latency [26]. Second, the stroke patients with SWAs showed far less spontaneous activity of their affected arm than the patients without SWAs and did not recover as much as assessed with the NIHSS, even though the two groups had similar demographics and similar sleep architecture. Thus, SWA seems to be related to a severe impairment of spontaneous activity of the affected arm in acute stroke patients. This finding supports previous studies showing that patients with focal SWAs suffer a worse outcome compared with patients without abnormal focal SWAs [5,27]. In a more general perspective, this observation accords with the notion that abnormal focal SWAs can be a marker of pathological conditions rather than a process of healthy aging [28].

The three cortical infarct patients who showed abnormal focal SWAs had infarct lesions in the same hemisphere, while the one subcortical infarct patient with SWAs presented the EEG abnormality in the hemisphere contralateral to the infarct lesion. This observation accords with recent findings using magnetoencephalography and probably relates to abnormalities of interhemispheric connections in such patients [29].

Although the number of patients are small, epileptiform activities occurred only in the patients with cortical infarcts but not in those with subcortical infarcts. This finding is in accord with the notion that seizures are more common in patients with cortical infarcts than those with subcortical lesions [30,31]. This is paralleled by differences in changes of cortical excitability in cortical and subcortical stroke patients [32,33]. Accordingly, electrophysiologic factors most likely reflect differences in affected cortico-subcortical circuitry and electrophysiological equilibrium. Interestingly, three of the four cortical stroke patients had similar lesion locations and volumes but showed quite different dynamics of motor recovery as compared with the patients with subcortical infarcts. If this was related to abnormal focal SWAs in the cortical stroke patients, the EEG may play an important role in future stroke management. Similarly, damage of the motor output system was found to be more predictive of recovery from hemiparesis than the lesion volume [34,35].

With regard to methodology, the current study had limitations. We did not explore dynamically the temporal evolution of EEG pattern over successive days. This, however, is very demanding for the patients and not applicable in the first days after stroke due to the medical requirements of the patients. Future work may benefit from coherence evaluation and connectivity analyses of the EEG data.

Conclusions

Our study supports the notion that stroke patients show abnormal sleep parameters, abnormal EEG patterns, and reduced spontaneous movement of activity of the affected arm during wakefulness. The change of spontaneous movement activity in the stroke patients was not apparent during sleep. Particularly, the stroke patients with abnormal focal SWAs presented with more severely reduced spontaneous movement activity of the affected arm as detected by continuous accelerometry.

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Conflicts of Interest: The authors declare that they have no conflict of interest.

References

1. Luu P, Tucker DM, Englander R, Lockfeld A, Lutsep H, et al. Localizing acute stroke-related EEG changes: assessing the effects of spatial undersampling. J Clin Neurophysiol. 2001, 18(4): 302-317.

2. Cyril Charlin, M.T., Urbain Calvet,Philippe Martinez,Vincent Larrue. The clinical significance of periodic lateralized epileptiform discharges in acute ischemic stroke. J Stroke Cerebrovasc Dis. 2000, 9(6): 298-302.

3. Jordan, K.G. Emergency EEG and continuous EEG monitoring in acute ischemic stroke. J Clin Neurophysiol. 2004, 21(5): 341-352.

4. Burghaus L, Hilker R, Dohmen C, Bosche B, Winhuisen L, et al. Early electroencephalography in acute ischemic stroke: prediction of a malignant course? Clin Neurol Neurosurg. 2007, 109(1): 45-49.

5. Arboix A, Comes E, García-Eroles L, Massons JB, Oliveres M, et al. Prognostic value of very early seizures for in-hospital mortality in atherothrombotic infarction. Eur Neurol. 2003, 50(2): 78-84.

6. Reith J, Jørgensen HS, Nakayama H, Raaschou HO, Olsen TS. Seizures in acute stroke: predictors and prognostic significance. The Copenhagen Stroke Study. Stroke. 1997, 28(8): 1585-1589.

7. Meinzer M, Elbert T, Wienbruch C, Djundja D, Barthel G, et al. Intensive language training enhances brain plasticity in chronic aphasia. BMC Biol. 2004, 2: 20.

8. Bassetti, C.L, M.S. Aldrich, Sleep electroencephalogram changes in acute hemispheric stroke. Sleep Med. 2001, 2(3): 185-194.

9. Vock J, Achermann P, Bischof M, Milanova M, Müller C, et al. Evolution of sleep and sleep EEG after hemispheric stroke. J Sleep Res. 2002, 11(4): 331-338.

10. Binkofski F, Seitz RJ, Hackländer T, Pawelec D, Mau J, et al. Recovery of motor functions following hemiparetic stroke: a clinical and magnetic resonance-morphometric study. Cerebrovasc Dis. 2001, 11(3): 273-281.

11. Siekierka-Kleiser EM, Kleiser R, Wohlschläger AM, Freund HJ, Seitz RJ. Quantitative assessment of recovery from motor hemineglect in acute stroke patients. Cerebrovasc Dis. 2006, 21(5-6): 307-314.

12. Uswatte G, Miltner WH, Foo B, Varma M, Moran S, et al. Objective measurement of functional upper-extremity movement using accelerometer recordings transformed with a threshold filter. Stroke. 2000, 31(3): 662-667.

13. Seitz, R.J., T. Hildebold, K. Simeria, Spontaneous arm movement activity assessed by accelerometry is a marker for early recovery after stroke. J Neurol. 2011, 258(3): 457-463.

14. Finnigan SP, Rose SE, Walsh M, Griffin M, Janke AL, et al. Correlation of quantitative EEG in acute ischemic stroke with 30-day NIHSS score: comparison with diffusion and perfusion MRI. Stroke. 2004, 35(4): 899-903.

15. Zhang SJ, Ke Z, Li L, Yip SP, Tong KY. EEG patterns from acute to chronic stroke phases in focal cerebral ischemic rats: correlations with functional recovery. Physiol Meas. 2013, 34(4): 423-435.

16. Giaquinto S, Cobianchi A, Macera F, Nolfe G. EEG recordings in the course of recovery from stroke. Stroke. 1994, 25(11): 2204-2209.

17. Finnigan SP, Walsh M, Rose SE, Chalk JB. Quantitative EEG indices of sub-acute ischaemic stroke correlate with clinical outcomes. Clin Neurophysiol. 2007, 118(11): 2525-2532.

18. Cuspineda E, Machado C, Aubert E, Galán L, Llopis F, et al. Predicting outcome in acute stroke: a comparison between QEEG and the Canadian Neurological Scale. Clin Electroencephalogr. 2003, 34(1): 1-4.

19. Jauch, E.C., et al., Guidelines for the early management of patients with acute ischemic stroke: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. Stroke. 2013, 44(3): 870-947.

20. Brott T, Adams HP Jr, Olinger CP, Marler JR, Barsan WG, et al. Measurements of acute cerebral infarction: a clinical examination scale. Stroke. 1989, 20(7): 864-870.

21. American Clinical Neurophysiology, S. Guideline 5: Guidelines for standard electrode position nomenclature. J Clin Neurophysiol. 2006, 23(2): 107-110.

22. Iber C, A.-I.S., Chesson AL Jr., Quan SF. The AASM manual for the scoring of sleep and associated events: rules, terminology and technical specifications. 1st ed. 2007, Westchester, IL.

23. Ahmed, I. Predictive value of the electroencephalogram in acute hemispheric lesions. Clin Electroencephalogr. 1988, 19(4): 205-209.

24. De Vries SI, Van Hirtum HW, Bakker I, Hopman-Rock M, Hirasing RA, et al. Validity and reproducibility of motion sen-

sors in youth: a systematic update. Med Sci Sports Exerc. 2009, 41(4): 818-827.

25. Cheung, V.H., L. Gray, M. Karunanithi. Review of accelerometry for determining daily activity among elderly patients. Arch Phys Med Rehabil. 2011, 92(6): 998-1014.

26. Terzoudi A, Vorvolakos T, Heliopoulos I, Livaditis M, Vadikolias K, et al., Sleep architecture in stroke and relation to outcome. Eur Neurol. 2009, 61(1): 16-22.

27. Hensel Hensel S, Rockstroh B, Berg P, Elbert T, Schönle PW. Left-hemispheric abnormal EEG activity in relation to impairment and recovery in aphasic patients. Psychophysiology. 2004, 41(3): 394-400.

28. Leirer VM, Wienbruch C, Kolassa S, Schlee W, Elbert T, et al. Changes in cortical slow wave activity in healthy aging. Brain Imaging Behav. 2011, 5(3): 222-228.

29. Tecchio F, Pasqualetti P, Zappasodi F, Tombini M, Lupoi D, et al. Outcome prediction in acute monohemispheric stroke via magnetoencephalography. J Neurol. 2007, 254(3): 296-305.

30. Lamy C, Domigo V, Semah F, Arquizan C, Trystram D, et al. Early and late seizures after cryptogenic ischemic stroke in young adults. Neurology. 2003, 60(3): 400-404.

31. Bladin CF, Alexandrov AV, Bellavance A, Bornstein N, Chambers B, et al. Seizures after stroke: a prospective multicenter study. Arch Neurol. 2000, 57(11): 1617-1622.

32. Hamzei F, Liepert J, Dettmers C, Weiller C, Rijntjes M. Two different reorganization patterns after rehabilitative therapy: an exploratory study with fMRI and TMS. Neuroimage. 2006, 31(2): 710-720.

33. Renner CI, Schubert M, Jahn M, Hummelsheim H. Intracortical excitability after repetitive hand movements is differentially affected in cortical versus subcortical strokes. J Clin Neurophysiol. 2009, 26(5): 348-357.

34. Page, S.J., L.V. Gauthier, S. White. Size doesn't matter: cortical stroke lesion volume is not associated with upper extremity motor impairment and function in mild, chronic hemiparesis. Arch Phys Med Rehabil. 2013, 94(5): 817-821.

35. Chen CL, Tang FT, Chen HC, Chung CY, Wong MK. Brain lesion size and location: effects on motor recovery and functional outcome in stroke patients. Arch Phys Med Rehabil. 2000, 81(4): 447-452.