# Laterality Coefficient: An EEG parameter related with the functional improvement in stroke patients

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***Abstract*— Stroke is one of the most prevalent pathologies around the world, with severe effects to the motor and sensory system that hinder the daily living activities. Brain Computer Interface (BCI) systems can help the stroke survivors to relearn the lost movements inducing neuroplastic changes in the affected motor cortex. The event-related synchronization and even-related desynchronization (ERD/ERS) calculated with the brain signals during the motor imagery tasks, could be related with the functional state of the stroke patients. The Laterality Coefficient (LC) is a parameter calculated using the ERD/ERS changes in the mu wave. The goal of this study is to test how useful the LC is for the functional assessment of stroke patients. Fifteen stroke patients with hemiparesis in the upper limbs have been enrolled on this study and performed 25 sessions of BCI therapy. All of them performed assessment sessions before and after the therapy. The results showed significant correlation between the LC and functional scales, like the Fugl-Meyer Assessment (FMA) or Box and Block Test (BBT). The LC could be a good biomarker for the functional assessment in stroke patients.**

***Keywords — Brain Computer Interfaces, BCI, EEG, Stroke, Rehabilitation, FMA, Laterality Coefficient, LC, ERD, ERS.***

## I. Introduction

Stroke is one of the most prevalent pathologies around the world, with severe effects to the motor and sensory system that hinder the daily living activities. The major part of the stroke patients need a long rehabilitation process to beat the hemiplegia and adapt again to the environment. New technologies like the Brain Computer Interfaces (BCI) are important tools to improve the functional results of the rehabilitation process. The BCI systems are able to measure the brain activation and to generate a control signal for external devices in real-time [1], [2]. After the stroke the brain signals do not follow a normal activation, usually the affected cortex presents less excitability due to the change in the cortical representation areas and other physiological alterations on the nervous tissue [3], [4].

However, these systems can help the stroke survivor to relearn the lost movements, using EEG signals during Motor Imagery (MI) exercises. The detected brain oscillations can be used to move a virtual reality avatar or trigger a functional electrical stimulator device to reproduce the imagined movement with the paretic limb. This way it provides the patient a closed loop feedback to ease the motor learning process.

During the MI tasks the patient should concentrate on performing an indicated movement mentally. At this moment typical brain waves appear in the EEG. During MI, the contralateral motor cortex produces a desynchronization (event-related desynchronization or ERD) of motor neurons, showing a decrease in the EEG amplitude in the frequency of 8-13 Hz (mu frequency rhythm). When the imagery period is finished, the contralateral motor cortex restores the synchronization state (event-related synchronization or ERS) and increases again the amplitude of the EEG [3]–[5].

Considering the stroke patients do not present normal brain signals, the ERD and the ERS patterns could be atypical as well. Kaiser et al. investigated the relation between these patterns versus the patient's functional state and spasticity using a new parameter, the Laterality Coefficient (LC) [4]. For functional assessment they used the European Stroke Scale (ESS), the Medical Research Council (MRC) and the Modified Ashworth Scale (MAS). The LC presented significant correlations with the MRC scale and MAS. The findings of Kaiser and colleagues showed that strong ERD patterns on the contralesional hemisphere are related to a high degree of impairment [4]. Other recent studies have analyzed this LC parameter with similar results [6], [7].

The objective of this study is to find correlations between the LC parameter in alpha and beta band, calculated using the ERD/ERS patterns, with other functional scales like the Fugl-Meyer Assessment (FMA) [8].

## II. Materials and Methods

### A. Study design

Fifteen stroke patients with upper extremity hemiparesis were recruited for this study. All these patients have been classified in four groups based on their stroke diagnosis: Cortical, Subcortical, Cortical + Subcortical and Unknown. The inclusion criteria were: i) able to understand written and spoken instructions, ii) residual hemiparesis, iii) the stroke occurred at least four days before the beginning of the study, iv) Functional restriction in the upper extremities, v) stable neurological status, vi) willing to participate in the study and to understand and sign the informed consent, vii) have the opportunity to attend meetings.

All patients have completed 25 sessions of BCI therapy, two sessions per week. Two assessment visits have been performed by an expert clinician before and after the therapy to track the therapy effect in the functional patient state. The Pre1 assessment is performed 1 month before starting the therapy, and Pre2 assessment is performed just before the therapy starts. Post1 is performed just after the last session, and Post2 is performed one month after the last session.

Table 1 shows the used scales for the assessments. In the first column appears the scales name, the second column is the short name of each scale, the column number three shows a short description of each scale and the last column presents the worst and best score. For the Fahn Tremor Rating Scale (FTRS) and BBT we have assessed both hands. For the BBT the patient is asked to move as many blocks as possible from one box to the contralateral box in less than 1 minute. In the case that the patient cannot move any block, the final score would be 0.

### B. *BCI System*

The BCI system used on this study is recoveriX® (g.tec medical engineering GmbH, Austria). The recoveriX system combines the visual feedback using a virtual reality avatar with a proprioceptive feedback using functional electrical stimulation (FES) [9].

Every patient performed 25 sessions of BCI training. The patient was seated in a comfortable chair with the arms on the table. In front of the patient was a computer screen, showing two hands in virtual reality. The total time of one session was about 60 minutes, including preparation and cleaning time. Every session was composed by up to 3 runs of 80 trials, depending of the patient's fatigue. Patients wore EEG caps with 16 active electrodes (g.LADYbird or g.Scarabeo, g.tec medical engineering GmbH). The electrode positions were according to international 10/10 system (extended 10/20 system): FC5, FC1, FCz, FC2, FC6, C5 C3, C1, Cz, C2, C4, C6, Cp5, Cp1, Cp2, Cp6. A reference electrode was placed on the right earlobe and a ground electrode at position of FPz.

Two FES electrodes were placed on the skin over wrist extensors of the left and right forearms. The stimulation parameters (g.Estim FES, g.tec medical engineering GmbH, Austria) were adjusted for each patient and session individually, to find the optimal passive movement without pain for patients with mild or moderate muscle spasm, or until muscle contraction was observed in the target muscle of their paretic side for patients with severe muscle spasm.

TABLE I. SCALES USED IN THE ASSESSMENT VISITS

| Assessment scales | | | | |
|---|---|---|---|---|
| ***Scale name*** | ***Short name*** | ***Description*** | ***Score*** | |
| | | | ***Worst*** | ***Best*** |
| Barthel Index | BI | Daily living activities | 0 | 100 |
| Fahn Tremor Rating Scale | FTRS | Degree of tremor | 12 | 0 |
| Modified Ashworth Scale | MAS | Spasticity | 4 | 0 |
| Box and Block Test | BBT | Grasp | Block's number | |
| Fugl-Meyer Assessment | FMA | Motor function on upper limb | 0 | 66 |

The frequency was set to 50 Hz, the pulse with to 300 µs.

Then, the therapist increased the current amplitude until the optimal stimulation point was observed.

The sequence of trials (motor tasks) was specified by the recoveriX software in pseudo random order. One single motor task is depicted in Fig 1. The patients first heard an attention beep . Two seconds later, an animated arrow with spotlight to the expected hand for motor imagery indicated the task of each trial with an auditory instruction saying either "left" or "right". When the recoveriX detected the appearance of the correct hand side, FES and avatar feedback were activated during the feedback phase. Feedback was otherwise deactivated. Updating the feedback was carried out five times per second. The animated forearm movement in avatar simultaneously performed the similar wrist dorsiflexion produced by FES.

The full recoveriX system is described in Fig. 2.

### C. *Laterality Coefficient analysis*

The EEG raw data recorded during the recoveriX sessions has been used to calculate the LC parameter.

The LC coefficient (1) is calculated for each session twice: one time for trials of MI of the paretic (p) hand and another time for the trials of the healthy (h) hand.

$$LC_{p/h} = (C-I) / (C+I) \quad (1)$$

Where C and I refer to the contralateral and ipsilateral values of the ERD/ERS patterns during the MI. C and I are calculated following these steps: 1) band filtering (8-13 Hz or 13-30Hz) of the EEG signal on the C3 and C4 electrodes. 2) Artifact rejection. 3) Laplacian derivation using the surrounding electrodes. 4) Calculate ERD/ERS patterns according to [10]. 5) Summation of all ERD/ERS values from second 2 until the end of the ERD map (second 8). And 6) apply the formula to obtain the LC coefficients.

## III. RESULTS

### A. *Participant baseline information*

The mean age of the participants was 55.27 years (±15.8), the time since the stroke was 7.43 years (±5.07). In terms of kind of stroke; six patients had a subcortical stroke, three had a cortical stroke, four a mixed cortical+subcortical and for two of them the kind of stroke is not clear. From the total number of patients, six of them presented a hemiparesis on the right side, and nine on the left side.

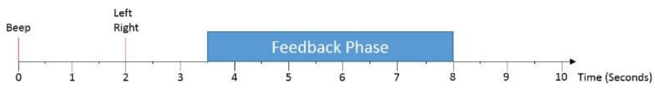


Fig. 1. Timing of one trial.

Fig. 2. Components of recoveriX system

*B. Functional scales*

The FMA mean before the therapy was 31.63 points, with an SD of ±20.46 points. The highest possible FMA score is 66. The BI mean was 88.33 (±16.86) points, the mean FTRS of the healthy hand was 0.13 (±0.39) points, the one of the paretic hand 7.27 (±5.15) points. The mean of the MAS scale of the wrist was 2.00 (±16.65) points, the MAS of the fingers 2.27 (±1.50) points. The mean of the BBT of the healthy hand was 60.08 (±15.39) boxes, and the same scale with the paretic hand was 9.92 (±11.59) boxes.

*C. LC variance*

Fig. 3 shows the variance of the LC parameter in alpha and beta band. In both bands, the LC of healthy hand (LCh) is strongly related with the results of the LC of paretic hand (LCp).

*D. Correlation with the functional scales*

Statistical analysis was performed using MATLAB R2015a. The Kolmogorov-Smirnov Test showed that this data does not follow a normal distribution [11]. Hence, for the statistical analysis we have used a non-parametrical method, the Spearman Test [12].

No significant correlations have been found between the LC of the beta band, or between the scales and the LCh in alpha band.

The average of the LC calculated during these 25 sessions in the paretic hand (LCp), shows significant correlations with the MAS scale, also with the BBT score of the paretic hand, and the FMA score.

Fig. 4 shows the correlation between the spasticity level of the fingers using the MAS, against the LC parameter of the paretic hand. Fig. 5 shows the correlation between the BBT score with the paretic hand and the LC parameter of the paretic hand. Fig. 6 shows the correlation between the FMA score and the LC parameter of the paretic hand.

The correlations present coherence amongst them. The results express that the high levels of functionality are related with LCp values near to 0. In the case of BBT and FMA, the correlations have a positive trend, as less negativity of the LCp, better results in the grasp and general function of upper limb. Nevertheless, the significant results of the MAS scale show a negative trend, that means the patients that have less spasticity (values near to 0 points) have LCp values near to 0.

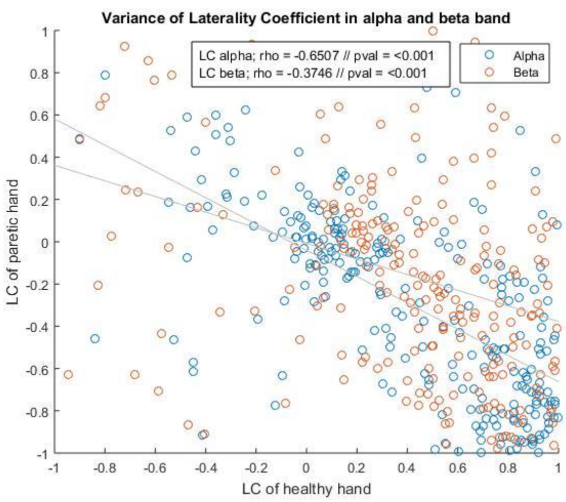


Fig. 3. Variance of LC parameter in Alpha and Beta band

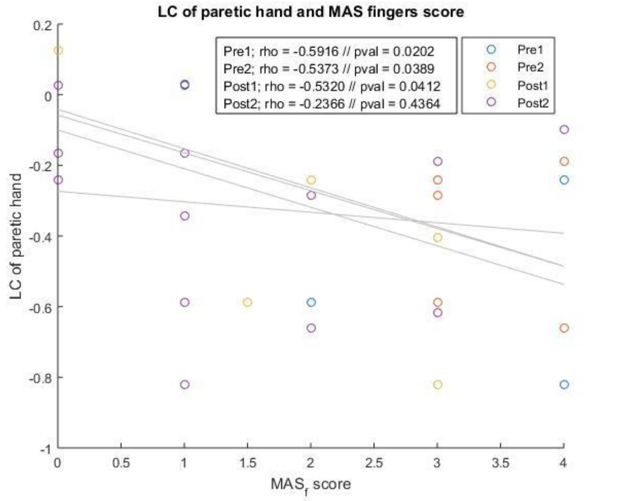


Fig. 4. Correlation between the LC of the paretic hand and the Modified Ashworth Scale of fingers.

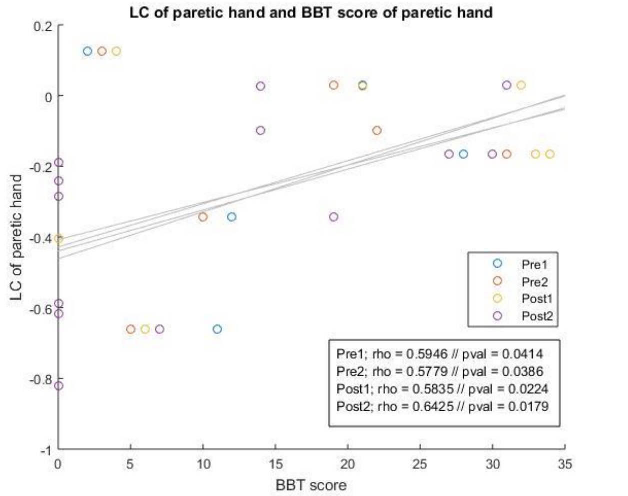


Fig. 5. Correlation between the LC of the paretic hand and the Box and Block Test.

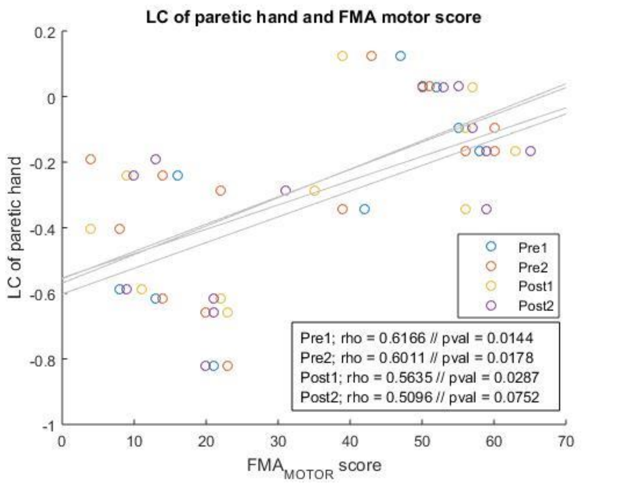


Fig. 6. Correlation between the LC of the paretic hand and the Fugl-Meyer Assessment of motor part.

Two of these correlations are not present in the Post2 assessment. MAS and FMA present good significance in Pre1, Pre2 and Post1 but not in the last assessment.

No significant correlations have been found with the other functional scales.

## IV. Discussion

The objective of this study was to find correlations between the LC parameter in the alpha band, calculated using the ERD/ERS patterns with the functional state of stroke patients. For this, we analyzed 15 stroke patients who performed 25 sessions of therapy with BCI system.

Usually the EEG parameters present high variability, but this is not the case for the LC parameter, as Fig.3 shows.

The LCp in alpha band show significant correlations with the level of spasticity, with the grasp function and with the global functionality of the upper extremity.

The first important result to point out is that our significant results of the LC against the MAS could reproduce the results presented by Kaiser et al. Our sample size is smaller than in the previous study, but the LC show a similar behavior on the same kind of patients. Our study results are also consistent with Park et al, and Belfatto et al, where the high values of FMA are related with a decrease of the LC [7].

Furthermore, the LCp is directly correlated with the grasp functionality of the affected hand (Fig. 4). These patients, having an LCp value near to 0, had better scores in the BBT. This correlation could be directly related to the last finding of the experiment, the relationship between the LCp parameter and the FMA score. The FMA is a very extended scale, used to evaluate the patient's functional state. FMA has been validated many times by many researchers, and the correlations between this scale with EEG features are not common. Even though the sample size in our study is too small to give conclusive results, it is worth to point out the significance of this finding.

The other used scales of this study did not present significant correlations with the LC parameter. Again, the sample size of our study could be a limitation to find such correlations.

Concerning to the LC of the beta band, and the LCh: they showed only some isolated significant correlations with the scales. After the analysis, the low values of the LCh parameter seems to be related with the high scores in the functional scales, but the correlations did not show significance of these relations.

Further studies with more patients will be needed to confirm these correlations and to find out how useful the LC parameter is in the daily clinical practice.

## V. Conclusion

The results of this study suggest that the LC parameter, calculated using the ERD/ERS of the stroke patients could be related with the Fugl-Meyer Assessment scale. This study opens the door to find more correlations between the EEG parameter with the patient's functional state.


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