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CORRELATIONS BETWEEN THE LATERALITY COEFFICIENT AND FUNCTIONAL SCALES IN STROKE PATIENTS

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ABSTRACT: Motor impairments are the most common and incapacitating consequences for the stroke survivors. As of today, the effects of this pathology in the central nervous system as well as the brain proprieties to restore the function are still not fully understood. The conventional physical therapy techniques are limited and sometimes have an innocuous effect for non-cooperative or strongly impaired patients who only can receive passive movement treatments. Brain Computer Interface (BCI) systems are adding new possibilities for the stroke patient's rehabilitation, helping the patients in the relearning process of lost movements, and inducing neuroplastic changes in the affected motor cortex. The electrical brain signals can provide valuable information about the brain functions, thence the BCI systems can process these signals to understand what is happening in each situation. 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. Twenty-six stroke patients with hemiparesis in the upper limb 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 findings of this experiment suggest that the LC parameter could be a good biomarker for the functional state of stroke patients.

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 needs a long rehabilitation process to overcome the hemiplegia and adapt again to the environment. The conventional rehabilitation techniques have a roof effect to get a complete degree of rehabilitation. 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, BCI systems can help the stroke survivor to relearn the lost movements, using EEG signals during Motor Imagery (MI) exercises [5]. 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 (e.g. [6], [7]). 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], [4], [8], [9]).
Considering the stroke patients do not present normal brain signals, the ERD and the ERS patterns could be atypical as well. Kaiser et al. [4] investigated the relation between these patterns versus the patient's functional state and spasticity, using a new parameter, the Laterality Coefficient (LC). 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].
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).

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MATERIALS AND METHODS

Study design: Twenty-six 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 between 23 and 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 possible 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.
The FMA scale has two different parts; the first part (up to 66 points) is for the motor assessment, and the other part is for the assessment of the sensation (up to 12 points).

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).
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. 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 the 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.
The frequency was set to 50 Hz, the pulse-width to 300μs.
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" in the patient's mother tongue. The patient started to imagine the movement and recoveriX processed the EEG using the features from a Common Spatial Patter (CSP) filter and using a Linear Discriminant Analysis (LDA) classifier to infer which hand the patient is imagining. If recoveriX detected the appearance of the expected 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 as produced by FES. The full recoveriX system is described in Figure 2.
Both hands are trained, the patient should learn the strategy used with the healthy hand to move the affected one. This is a key point for a correct embodiment and activate the motor learning process.

Assessment scales

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

Table 1: Scales used in the assessment visits

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.

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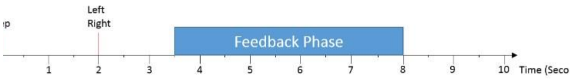

Figure 1: Timing of one trial.

Figure 2: Components of the recoveriX system.

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

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 [9]. 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.

RESULTS

Participant baseline information: The mean age of the participants was 61.5 years (±12.8), the maximum age was 86 years, and the minimum was 33 years old. The mean time since the stroke was 4.2 years (±4.8), the maximum time since stroke was 24 years, and the minimum 10 months. In terms of kind of stroke; fourteen patients had a subcortical stroke, one had a cortical stroke, five a mixed cortical+subcortical and for six of them the kind of stroke is not clear. From the total number of patients, eight of them presented a hemiparesis on the right side, and eighteen on the left side.

Functional scales: The FMA mean before the therapy was 23.08 points, with an SD of ±16.99 points. The highest possible FMA score is 66. The BI mean was 78.46 (±21.45) points, the mean FTRS of the healthy hand was 0.53 (±2.00) points, the one of the paretic hand 8.98 (±4.83) points. The mean of the MAS scale of the wrist was 1.76 (±1.34) points, the MAS of the fingers 2.11 (±1.12) points. The mean of the BBT of the healthy hand was 56.67 (±14.38) boxes, and the same scale with the paretic hand was 4.96 (±11.90) boxes.

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).

LC during BCI therapy: Fig. 4 shows the delta of the LC parameter calculated in the alpha band during the BCI therapy. Typically, the LC delta in both hands goes to values near 0 through the therapy.

The LCh and LCp delta are a mean of the delta of each participant. Two of these participants only performed 22 sessions of BCI therapy, for external problems no

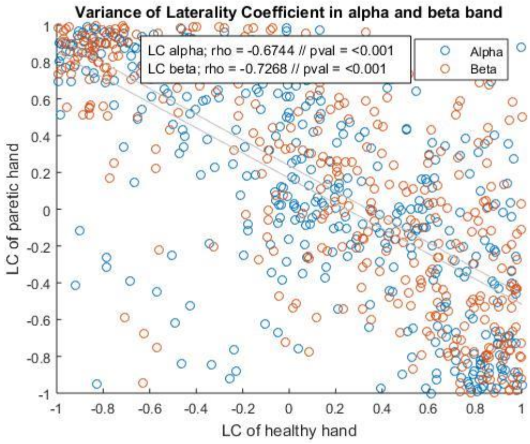

Figure 3. Variance of LC in alpha and beta band

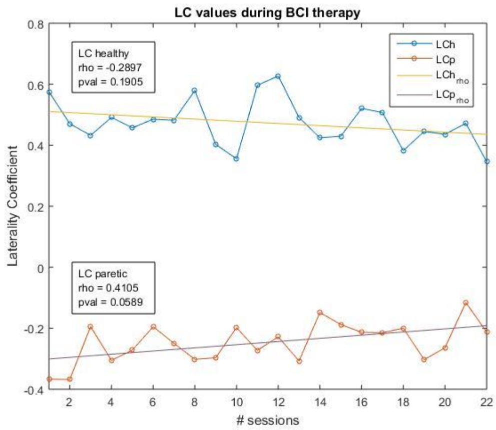

Figure 4. LC parameter in alpha band during BCI therapy

related with the study. For this reason, the Fig.4 only shows the LC behavior between session 1 to session 22.

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. Hence, for the statistical analysis we have used a non-parametrical method, the Spearman Test.

No significant correlations have been found between the functional scales and the LC of the beta band.

The average of the LC calculated during these 25 sessions in the healthy hand (LCh), shows significant correlations with the FTRS score of the paretic hand, also with the BBT score of the paretic hand, and the FMA of the motor part and the FMA of the sensation part.

The average of the LC calculated during the therapy in the paretic hand (LCp) shows correlations with the BBT of the paretic hand, and the different parts of the FMA scale.

Laterality Coefficient of the healthy hand: Fig. 5.A shows a moderate relation between the tremor degree of the paretic hand using the FTRS, and the LC parameter of the healthy hand. This correlation is present in all the assessment (pre and post) less on Pre2 assessment, where the p-value is near to 0.05.

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Finally, there are significant correlations between this parameter and the FMA scale. On the Fig. 5.B appears the relationship between the LCh and the FMA_motor.
Fig.5.C shows the relation of this parameter and the sensation part of the FMA scale.

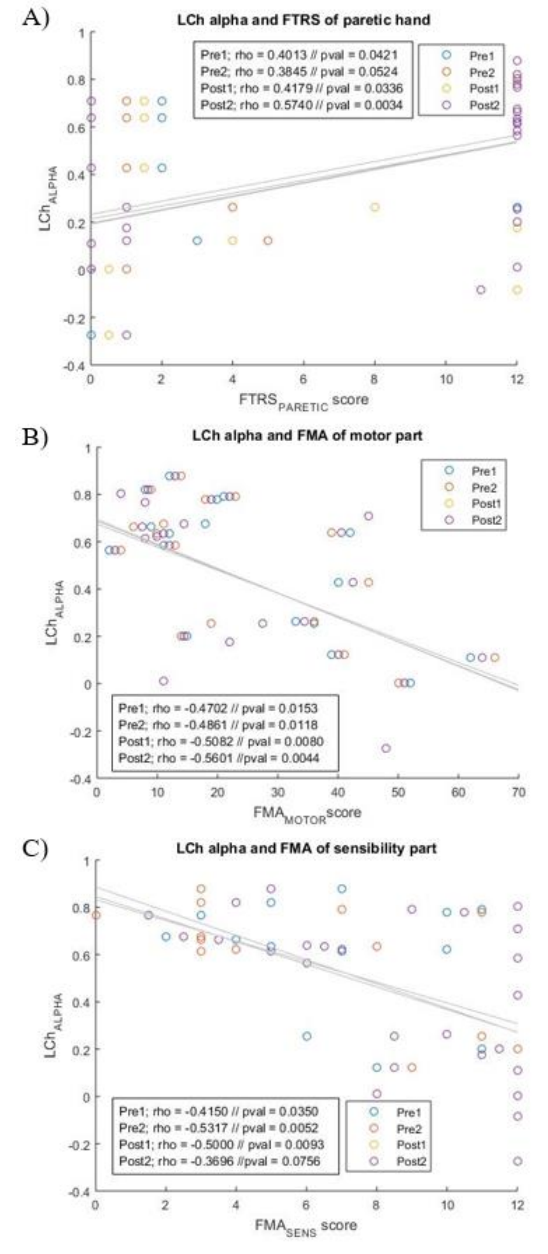

Figure 5. Correlation of LCh and functional scales

Laterality Coefficient of the paretic hand: The BBT on the paretic hand, also present a significant relation with the LCp, but in this case the correlation is present in all the assessment except on Pre2 (Fig. 6.A).
In Fig. 6.B appears the correlation between LCp and the FMA_motor. The correlation is only significant in the two post assessment visits, in the case of the other non-significant cases (Pre1 and Pre2), the p-value is near to 0.05 points.
Finally, in Fig. 6.C appears the correlation with the sensation part of the FMA scale.

The correlations present coherence amongst them. The correlation coefficients express that the high levels of functionality are related with LCp values near to 0, and the low functional levels are related with very negative LCp values. Furthermore, the LCh have the opposed sign on the correlation coefficient with the scales.

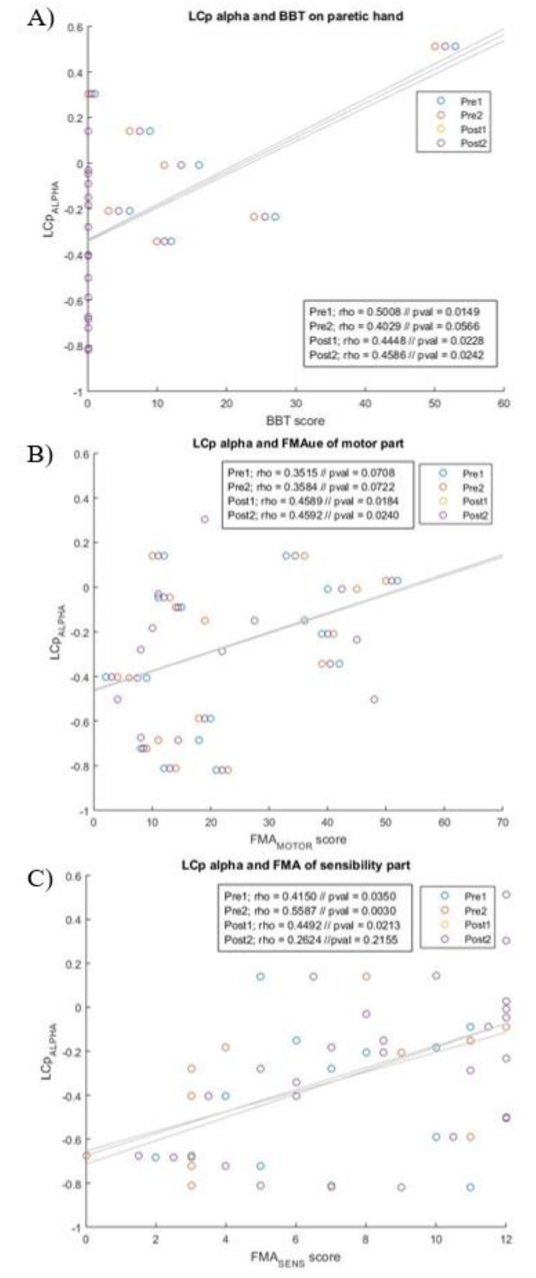

Figure 6. Correlation of LCp and functional scales

In terms of the used functional scales, the high scores are related with values near to 0 in LCh and LCp, and the low scores with values near to 1 of LCh, and -1 in LCp. The FTRS is a special case of this typical positive or negative trend related with the LCh or LCp, because on the FTRS the high score is related with high degree of tremor.

DISCUSSION

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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 26 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 LCh in alpha band shows significant correlations with the tremor degree, with the global functionality of the upper extremity and with the sensation part of the FMA. In the other hand, the LCp in alpha band shows a marked correlation with the grasp functionality (Fig. 6.A), with the global motor function in the upper extremity (Fig. 6.B) and the sensation degree (Fig.6.C).
The general rule that can be applied to all these correlations is: LC values near to 0 points are related with high functional degree. LCh values near to 1 and LCp values near to -1 are related with poor functional degree.
The first important result to point out is that our significant results of the LC against the MAS are not similar to the results presented by Kaiser et al. The different kind of stroke patient, or the sample size could explain this.
Another important finding is the correlation with the FMA motor 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. This correlation is especially interesting because it could mean that the quantification of the cortical activation, using the LC parameter is related to the peripherical motor performance. This relation is present in the affected hemisphere and also in the healthy hemisphere. The healthy hemisphere is not related directly to the motor activity of the paretic side, but for the LC calculation it is necessary using and compare the signals of both hemispheres. This is a reason why the LCh are important values for the assessment of the paretic side. 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.
And last but not least, the LC alpha also presented a strong correlation with the FMA sensation scale part.
The superficial sensitivity and the proprioception are essential players on the BCI systems. The patients should feel as much as possible the feedback that the system provides for a correct closed loop interaction. Only if a correct synchronization between the intention of movement and the real feeling of this movement is provided the motor learning process is optimal [10]. This is only possible with BCI, and this is the greatest limitation of the conventional therapy techniques like the mirror therapy.
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 the LC of the beta band, it shows only some isolated significant correlations with the scales.
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.

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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