Analysis of cortical power distribution as a function of the typewriting skill

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ABSTRACT

The present study aimed to investigate alterations in EEG patterns in normal and right-handed individuals, during the process of learning a specific motor skill (typewriting). Recent studies have shown that the cerebral cortex is susceptible to several changes during a learning process and that alterations in the brain's electrical patterns take place as a result of the acquisition of a motor skill and memory consolidation. In this context, the subjects' brain electrical activity was analyzed before and after the motor task. EEG data was collected by a *Braintech 3000* and analyzed by *Neurometrics*. For the statistical analysis, the behavioral variables "time" and "number of errors" were assessed by a one-way ANOVA, block as main factor. For the neurophysiological variable "absolute power", a paired t-test was performed for each pair of electrodes CZ-C3/CZ-C4, in the theta and alpha frequency bands and for O1-P3/T3-F7 in the beta band. The main results demonstrated a change in performance, through both behavioral variables ("time" and "number of errors"). At the same time, no changes were observed for the neurophysiological variable ("absolute power") in the theta band. On the other hand, a significant increase was observed in the alpha band in central areas (CZ-C3/CZ-C4) and a reduction in the beta band in temporal-parietal areas (O1-P3/T3-F7). These results suggest an adaptation of the sensory-motor cortex, as a result of the typewriting training.

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INTRODUCTION

A growing flow of information has been generated with regard to the mechanisms involved in the acquisition of new motor patterns. In this context, learning and memory are shown strongly associated between one another. The acquisition of new skills that bring as result a behavior modulation is proper of learning, while the retention of this skill involves memory aspects[(1)]. Thus, both processes share similar neural mechanisms that equally participate in the attention control, sensorial integration and perception[(2)].

The procedural memory is a result of the increase on performance and proportionally of the increment on the motor gesture accuracy[(3)]. It may be understood as the motor or sensorial ability that we usually call as "habit"[(4)], presenting relation with the motor procedures responsible for the acquisition of that kind of memory. Learning progressively produces a decrease on the number of error related to the task, an increase on coordination and higher agility and speed on the execution of the movement[(5)]. The comprehension of experimental models related to the filing of motor information is guided by the phenomenon of neural plastic arrangements of the nervous system. The combination between sensorial memory (sensorial stimuli), short-term memory (work memory) and long-duration memory represented in the nervous system through the consolidation and execution of the motor gesture would lead to a new ordering in the neural configuration[(6,7)]. Particularly, during the learning process of a motor task, this internal representation would produce an increment on the synaptic efficiency ("power") of neurons in cortical and subcortical areas[(8)]. The elaboration of an internal model from the motor learning is supported on the connectivity and organization of a new neural net[(9)]. In the traditional model of Donald Hebb, ideas about synaptic reverberations are postulated, in other words, sequences of neuronal chains are formed from learning[(10,11)]. Such chains represent distinct information distributed along the cortex, being responsible for habit mechanisms, memory retention and lesions recovery (neuronal plasticity).

In this context, experiments conducted in the last two decades demonstrated a strong relation between the ideas of Hebb and learning basic neuronal processes: long-term potentiation (LTP) and long-term depression (LTD)[(11-13)]. In these situations, the information consolidation would occur basically due to biochemical events[(14)]. Mathematical models reinforce the theories described by Hebb[(15,16)].

Many are the reasons that justify the performance of an experimental model as the model proposed in this work. The literary void with regard to the items surveyed as theoretical references up to the fact of the own experimental model as a whole are both distinct from the several models involving motor learning. Many other aspects involved in the model make it relevant. The incorporation of the motor gesture from the repetition of the motor activity produces neuronal alterations able to be detected with the use of the quantitative electroencephalography (EEGq)[17]. Particularly, the behavior of these frequency bands will be observed in scalp areas that represent the primary somatosensorial cortex (CZ-C3/CZ-C4), visual areas, the posterior parietal cortex, body spatial representations (O1-P3) and secondary motor areas (T3-F7). The alpha frequency bands have been correlated to cognitive processes, particularly fast alpha band (10 and 12 Hz)[18]. It seems that this frequency modifies when the subject is exposed to cognitive tasks of the most different complexity levels[19]. The beta band is considered as a frequency fast wave (12 to 30 Hz) and it seems that it is the one most related with motor activities, either pre-motor activities or motor activities themselves. Such frequency presents considerably value for the analyses of the normal and pathologic movements[20,21]. The theta frequency band is associated to attention and automatism processes, being directly correlated with long-term potentiation and long-term depression mechanisms that are the biochemical basis of the learning process[22,23]. In this context, the objective of the present study was to investigate the influence of the learning of a motor task in the reorganizing of cortical maps, especially to identify alterations on the EEGq absolute power related to cognition (alpha), attention (theta) and motor function processes (beta) during the typewriting learning process.

METHODOLOGY

Sample

The sample was composed of 29 subjects (14 male and 15 female) with ages ranging from 20 to 40 years. The subjects, selected among Graduation and Master of Science students of the Castelo Branco University (CBU) did not present any type of involvement of mental and physical health, healthy, free of any cognitive deficit and making no use of psychotropic or psychoactive substances. With the objective of reaching this purpose, a detailed questionnaire was applied in order to identify and to exclude any subject that could contaminate future results. The individuals had no previous experience on typewriting and the laterality was used as exclusion criterion. To do so, the Edinburgh inventory[24] was applied in order to verify the predominance of participants (right-handed versus left-handed). Individuals predominantly left-handed were excluded from the experiment. The subjects signed a free consent from containing details of the experimental condition and approved by the CBU Ethics Committee.

Experimental procedure

The room used for the receiving of the electroencephalographic signal was prepared for sound isolation and the lights inside the room were reduced during the data acquisition. The subjects sat down comfortably in chair with arm support with the objective of minimizing muscular discomfort. The chair was set at a distance of approximately 40 cm from the table and adjusted according to the forearm of each individual. An old typewriter (*Olivetti Linea 98*) was set on the table where the motor task was performed. The typewriter keyboard was covered with a "wooden box" in order to avoid participants to have visual information about the hands position and forcing them to create a "spatial reference" for the keyboard.

The task was composed of a typewriting method, Celso Santos[25], of progressive learning, which training was performed in a single day. This method has been used and approved as effective for years in different typewriting courses (previous consultation). The method consists of exercises that initially expose the learner to simple gestures that progressively increase in complexity, thus allowing the individual to amplify progressively his skillfulness and bimanual coordination. The lessons were fixed to a corkboard placed at the wall in front of the participants and, as the individuals ended the lesson, the next lesson was fixed to the corkboard. Each block of exercise was composed of 10 columns and 12 lines (matrix 10 x 12) and each participant was forced to perform four blocks of this matrix to fulfill one lesson. The participants were instructed to perform the task as fast and effectively as possible. The total time for the performance of the four blocks and of each block individually was measured. This way, it would be possible to verify whether or not a progressive improvement between blocks occurred. The number of errors was recorded specifically in each block and the sum of all. So, the progressive improvement of the motor gesture and the decrease on the number of errors were estimated.

In the present experiment, the subjects performed the typewriting technique for one hour, rested for 20 minutes and performed one more hour of motor task (total of two hours). At the end of each hour, if the exercise had not been completed, the exercise was not considered. This rule is necessary so that each subject had exactly one hour in each training period. Finally, paper sheets A4 (210 x 297 mm) were set at the typewriter before the beginning of the task. The participants were instructed to perform two blocks per sheet. At the end of the second block the sheet was replaced by another one. The subjects were submitted to experiment always in the afternoons, about two or three hours after their meals.

Data acquisition

For the receiving of the electroencephalographic signal, the device *Braintech 3000* (Emsa – Medical Instruments, Brazil) was used. This system uses an analogical/digital converter plate (A/D) of 32 channels with resolution of 12 bits, placed in a *Pentium III* ISA slot with processor of 750 Hz. The electrophysiological signals were filtered between 0.01 (low-pass) and 100 Hz (high-pass), with a sampling ratio of 200 Hz. The data acquisition software called *EEG Captação* was used (Emsa-Delphi 5.0) with filter *Notch* of 60 Hz and cut filters of 0.3 Hz (high-pass) and 25 Hz (low-pass). The international 10/20 electrode system[26] was used for the placement of 19 monopolar electrodes along the scalp (areas: frontal, temporal, parietal and occipital) and one electrode in each earlobe. The electrodes were assembled in a nylon cap (ElectroCap Inc., Fairfax, VA) with the 10/20 system pre-fixed. This system regards a standard for electrode placement internationally established, which uses anatomic marks to delimit the placement and distance between electrodes. The cap was placed and adjusted individually in each participant according to the heads' circumference (caps of several sizes). The earlobes were used as reference (biauricular). The signal acquired in a given electrode is a result of the difference between its electric potential in the scalp and the preestablished reference. The impedance levels of each electrode were initially verified, which values should be between 5 and 10 K ohms (Ω) and kept within this range. The signals acquired should present the total amplitude (peak to peak) lower than 100 μV. For this reason, the signal was amplified with gains of about 20.000. The electroencephalographic signals obtained ranged from 0.01 to 50 Hz. The ocular electric activity was estimated with the placement of two electrodes of 9 mm of diameter assembled in a bipolar way. The electrodes were positioned above and below the right eye orbit, respectively, in order to record the vertical ocular movements and at the outer side of eyes, in order to record the horizontal ocular movements. The electrodes measure the so-called "eyes blink effect", which are eyes blinking movements that occur naturally. Such beats influence the signal receiving, especially in the frontal electrodes (FP1-FP2). The visual inspection of data for the removal of errors is performed in function of the recording of the ocular electric activity. For such procedure, a visualization program called *EEG Telas* (Emsa-Delphi 5.0) was used. The electroencephalographic data were obtained according to model previously described at two moments: before typewriting task and after the end of training. There was no signal acquisition during motor task.

Data analysis and calculation of the dependent variables

Two types of variables were analyzed in the experiment: behavioral and neurophysiological variables, being the last ones extracted from the quantitative electroencephalography (EEGq). The behavioral variables that measured performance were given through the execution time of blocks and number of errors in each block. After the data collecting and respective filing, the analyses for the extraction of the dependent variables were recorded. After visual inspection for the removal of possible errors, the electroencephalographic signals were processed through software called *Neurometrics* (NxLink, Ltd., USA), which extracted the neurophysiological variable relevant to the experiment from the data, in other words, from the temporal series: distribution of absolute bipolar power in homologue electrodes positioned in different hemispheres (right x left). It is understood as distribution of absolute bipolar power the measures that reflect the power gradient between a pair of electrodes[22].

Measurement of the behavioral and electrophysiological variables

The behavioral and electrophysiological variables were collected in distinct situations: the behavioral variables were collected during the task execution and the electrophysiological variables before and after the motor task, respectively. Specifically, the behavioral parameters, the execution time and the number of errors in the typewriting task were recorded during the motor training. These parameters were obtained during each block. This way, four blocks were recorded for each exercise performed. For analysis purposes, the four first blocks of exercise 1 were considered, once all individuals fulfilled the exercise. Particularly, the time was measured from the beginning (initial typing of key ***a)*** until the end (initial typing of key ***h)*** in each block of exercise independently. The electrophysiological measure (electroencephalography) was recorded before and after the performance of the four blocks of typewriting task, in other words, no electrophysiological measures occurred during the motor task.

Spatial localization and frequency bands

Many cortical regions could be selected in an experiment with this design. Particularly, pairs of electrodes representative of motor-sensory areas were selected, once the task requires demands from the motor and sensory systems. The selection of EEG frequency bands, previously selected, is associated with possible alterations produced by the motor learning process. The gesture automation, from the electrophysiological point of view, is associated with cognition (alpha) and attention (theta) mechanisms and with motor skills (beta)[17]. Areas of interest such as the areas representative of the primary somatosensorial cortex (CZ-C3/CZ-C4), the parietal-occipital cortex (O1-P3) and secondary motor areas (T3-F7) were then selected. These areas respectively represent the area of sensorial interpretation of stimuli received by the touch of fingers in relation to the typewriter keys (CZ-C3/CZ-C4). The parietal-occipital region is related with spatial-temporal and visual-perceptive attention processes[27,28]. The secondary motor areas function as planner and organizer of the sequence of movements to be performed by the hands of the subject[29-36].

Absolute power

Power is an amplitude measure: the higher is the amplitude, the higher the amount of power in the electroencephalographic signal will be. The absolute power is expressed in peakwatts (μV^2) and reflects the amount of energy present in a given frequency band in a specific pair of electrodes. The *Neurometrics* analyzes the power distribution in the scalp. Specifically, through this program, the power variation between pairs of electrodes is checked.

Statistical analysis

Due to the fact that electrodes hold differentiated spatial position in the scalp, an independent statistical analysis was selected. In behavioral variables, the one-way analysis of variance ANOVA was used with the objective of identifying differences between the four blocks of exercise 1. In case the factor block (main effect) is significant source of variance, the post-hoc Scheffé analysis will be used. The EEG data were measured at two different moments: before and after the beginning of the task (typewriting). This way, a paired t-test was applied with the objective of verifying whether the typewriting learning process produces significant alterations in the absolute power.

RESULTS

Behavioral variables

With regard to the time spent in each one of the four blocks, the statistical analysis demonstrated that the factor "block" is significant source of variance ($F_{(3.25)}$ = 8.181; p = 0.000). Therefore, a modification between block 1 (average = 13.52/standard deviation = 5.27) and block 2 (average = 10.38/standard deviation = 4.52); block 1 and the third and fourth blocks (average = 8.74/standard deviation = 2.67; average = 7.65/standard deviation = 2,37), respectively, was proposed (figure 1).

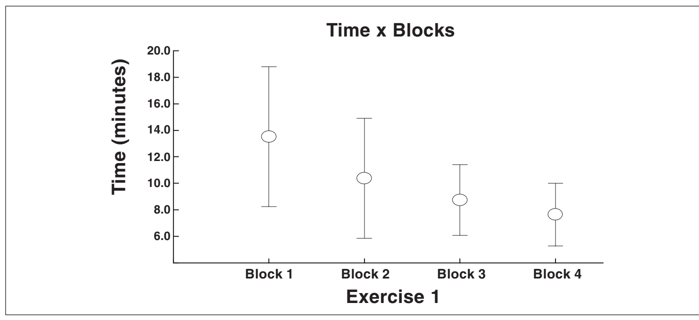

Fig. 1 *– Relation between task execution time and blocks: the graphic above represents the total time (average/standard deviation) spent to perform the motor typewriting task in each one of the blocks (total of four blocks). One observes improvement on execution of the task under the behavioral point of view (* values p between blocks equal to 0.000), once the subject reduced the time spent with the motor task along the training stages (blocks).*

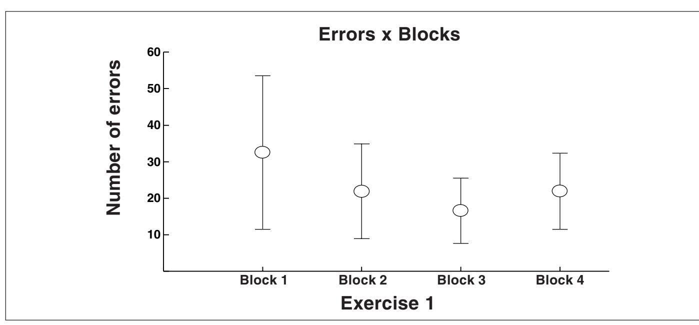

Fig. 2 *– Relation between number of errors and blocks: the graphic above represents the relation between the total number of errors (average/standard deviation) in the performance of the motor typewriting task in each one of the four blocks (* values p between blocks equal to 0.000). One observes a drop on the number of errors with regard to this behavioral variable, what suggests an improvement on the motor performance during the motor practice.*

With regard to the number of errors in all blocks, the statistical analysis demonstrated that the factor "block" is significant source of variance ($F_{(3.25)}$ = 8.181; p = 0.000). Therefore, a modification between block 1 (average = 32.51/standard deviation = 21.01) and block 2 (average = 21.89/standard deviation = 12.96); block 1 and the third and fourth blocks (average = 16.58/standard deviation = 8.92; average = 16.62/standard deviation = 10.42), respectively, was proposed (figure 2).

Neurophysiological variables

The absolute power variation between pre and post training periods was analyzed in different regions and bands: CZ-C3 and CZ-C4 in theta and alpha bands and in electrodes O1-P3 and T3-F7 in beta band (figures 3 and 4).

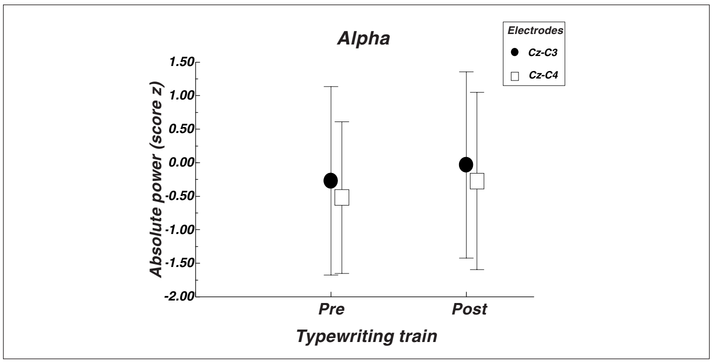

Fig. 3 *– Absolute power variation in function of the typewriting training: figure above describes the variation of the alpha frequency band (average/standard deviation) between electrodes CZ-C3 (p = 0.022) and electrodes CZ-C4 (p = 0.036). One observes a significant increase on the absolute bipolar power in the post-typewriting training condition in relation to the pre-typewriting training condition (* values of $p \leq 0.05$).*

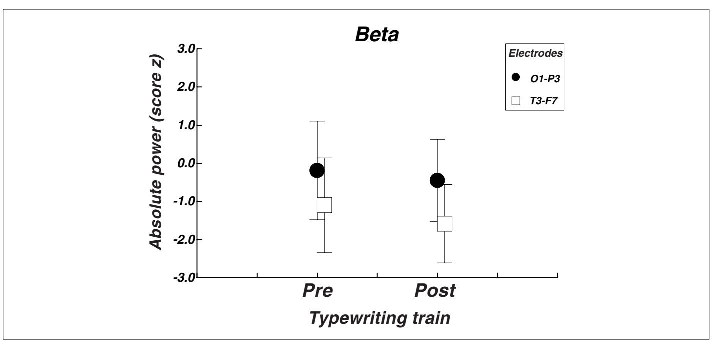

Fig. 4 *– Absolute power variation in function of the typewriting training: graphic above describes the variation of the beta frequency band (average/standard deviation) between electrodes O1-P3 (p = 0.025) and electrodes T3-F7 (p = 0.016). One observes a significant decrease on the absolute bipolar power in the post-typewriting training condition in relation to the pre-typewriting training condition (* values of $p \leq 0.05$).*

DISCUSSION

The present study investigated alterations in the EEGq absolute power related with cognition (alpha) and attention (theta) processes as well as motor functions (beta) in individuals submitted to a typewriting learning process. The behavior of these frequency bands was observed in the scalp areas that represent the primary somatosensorial cortex (CZ-C3/CZ-C4), the parietal-occipital cortex (O1-P3) and secondary motor areas (T3-F7). The use of the traditional typewriter in the present study was justified due to the fact that it requires higher force applied to the keyboard if compared with a computer keyboard, for example. This way, the representation in the cerebral cortex trends to increase, making the electroencephalographic measures more prominent[37-39]. The number of errors (behavioral variable) is particularly relevant, once the number of errors decreased as the subjects became more skilful in function of the typewriting learning process. The same may be considered for the time spent for the execution of each block. Essentially, the results standards were emphasized between the first block and the others. In this context, the behavioral results reproduced previous findings in which an increase on the performance was observed when individuals were exposed to a given motor-sensory task[5,17]. The improvement on performance (time x error) seems to be associated with a better management of information extracted from the procedural memory[17]. Besides, based on the present results, a "critical period" during the learning process in the transition between the first and the second blocks in both variables (time x error) was clearly characterized. These findings suggest that this "critical moment" was associated with the transition between the control mechanisms and the movement automation. Control mechanisms are present at the initial phase of the learning process, where individuals need to allocate an excessive dose of attention to perform the motor gesture. On the other hand, once the task becomes automatic, this excessive dose of attention is no longer required.

The association between quantitative electroencephalography and typewriting learning process makes this study innovative, once there are no reports in literature about such association. Neurophysiological aspects such as motor activation, spatial memory, attention, among others, are evoked and improved through the respective learning process. In turn, the quantitative EEG technique from different frequency bands seems an instrument sensitive to such aspects. EEGq could monitor changes in the cerebral state that occur when the individual performs a motor-sensory activity[17]. Specifically, alterations on the EEG temporal series could be correlated with the neural reorganization, which is involved in the construction of complex motor skills[5]. Despite the low EEG spatial resolution, such data present excellent temporal capacity. Thus, the repetition imposed by the training period could be observed through the EEG patterns.

In the present research, the frequency bands theta (4.0-7.5 Hz), alpha (8-12 Hz) and beta (13-35 Hz) were used to evaluate attention and cognitive changes produced by the motor-sensory task (typewriting). Specifically, the absolute power measures were used with the objective of observing possible cortical alterations. Absolute power would express the energy present in one band, regardless all other frequencies in the range of the spectrum. Thus, the present results demonstrated a simple reduction on the absolute power between pre and post-training periods in the theta band with no statistical difference in central areas (CZ-C3)/(CZ-C4). The inexistence of alterations in theta may be explained due to the fact that the experimental design was performed in pre and post-training periods, and no electroencephalographic measures was performed during the motor task. So, the possible alterations in theta (attention) that probably occurred during task were not observed. It is worthy emphasizing that the most significant blocks in this model (1 and 2) as well as all other blocks of the other exercises were performed without electroencephalographic measurement during the task. Our results, which were in disagreement with other experiments, could not demonstrate an expected increment of theta in function of the motor learning process[17]. Supposedly, the modifications in such frequency band in the central areas (CZ-C3)/(CZ-C4) are associated with the involvement of the supplementary motor area (SMA), pre-motor cortex (PME) and somatosensorial cortex (SMC) in processes involving attention[40].

On the other hand, significant differences were found in the same electrodes in the alpha band. An increment between pre and post-training periods was verified during the experiment. This increment on the absolute power (alpha band) between the base line (pre-treatment) and the second measure suggests the learning consolidation[17]. The presence of alpha rhythms reflects attenuation on the cortical neuronal activity and hence the amplitude of this rhythm is inversely proportional to the neural activity of a pre-established population in a given cortex area. In this context, an increase on the absolute power in the alpha band after the motor learning process may be interpreted as a reduction on the neurons activity in the specified region, thus showing a neural specification.

The Greek letter "beta" means frequencies above 13 Hz. Beta rhythms are primarily found in frontal and central areas of the scalp and generally do not exceed 35 Hz[40-43]. This rhythm is blocked by motor activities or tactile stimulation[44].

The results indicate a decrease on the beta activity between the pre and post-training periods. Traditionally, increases or reductions on the beta activity have been exploited through a specific paradigm, also known as event-related synchronization (increase) or desynchronization (reduction). In this context, increases or reductions would be associated with the signal amplitude[17]. In the present experiment, the power reduction in beta occurred in areas from the left hemisphere that command movement in segments in the left side of the body. The regions submitted to such modifications after task (typewriting) are close to motor areas that perform and plan the motor actions (T3-F7). A reduction on absolute power in beta was also observed in other sectors of the scalp involved with visuospatial and temporal mechanisms (O1 and P3). Supposedly, the activations of these two last regions are associated with the nature of the task, which stimulates the individual to develop a visual feedback and memory, represented by their positioning in relation to the keyboard.

CONCLUSION

The present study concludes that such experimental model emphasizes the effective motor learning process according to the variables analyzed. In this context, further studies should be conducted with the objective of investigating experimental models that complement our findings, maybe with improvements in the model or in the form of signal acquisition.

All the authors declared there is not any potential conflict of interests regarding this article.

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