International Journal of Bioelectromagnetism *www.ijbem.org*
Vol. 14, No. 2, pp. 108 - 114, 2012

Improving flight simulation performance by using tDCS stimulation

Gianluca Borghini[a], Giovanni Vecchiato[ab], Viviana Ponzo[a], Giacomo Koch[a]
Roberto Isabella[c]
[a] IRCCS "Fondazione Santa Lucia", Rome, Italy
[b] Dept. Physiology and Pharmacology, Univ. of Rome –Sapienza-, Rome, Italy
[c] Direzione Generale della Sanità Militare, Rome, Italy

Correspondence: G Borghini, IRCCS Fondazione Santa Lucia, via Ardeatina, 306, 00179, Rome, Italy. E-mail: gianluca.borghini@gmail.com, phone +39 349 311 25 48

Abstract. The aim of this work is to demonstrate if the transcranial direct current stimulation (tDCS) should be useful to improve the performance of subjects while they are engaged in a flight simulation and, at the same time, in other secondary tasks. The evaluation of the flight performance is done by analyzing the pitch and bank angles respect to an ideal flight path that the subject learnt during the training sessions, while the tasks of alert and vigilance (TAV), the secondary tasks, are estimated by analyzing the reaction times and the error rates. Before the experiments the subjects receive a tDC stimulation, but they do not know about the possibility of a 'fake' stimulation (Sham condition), during which the tDCS device automatically turns off after few seconds. By comparing the performances of the two experimental conditions, with and without the tDCS, it is possible to find out if this kind of stimulation could help the enhancement of the performance before real operational missions. Also, the results are compared to the NASA-TLX scores for checking if the subjective workload evaluations have any relations with the performance levels of the two experimental conditions.

Keywords:Flight Simulation, Current Stimulation, tDCS, Workload, Attention, Vigilance, Pilots.

1. Introduction

There are many methodologies for improving the performance of professional drivers, as pilots. For example, by training and exposing them to new operational conditions. After these steps, they reach a saturation of the performance level and it becomes hard to overpass it. It is well known how in operational environments as in the military aviation, the performance level has to be maintained very high and the pilots are always under pressure, especially during strategic missions. The question is: are there any methods by which it should be possible to improve, even for a while, the skills of the pilots? Technologies as the tDCS could help to complete a task or a mission, improving the performances in a non-invasive and quickly way. In fact, it can selectively stimulate the brain and improve the function of such area. As result, it will be possible to improve the efficiency of the operators while they are doing their jobs.

1.1. Trascranial direct current stimulation

The transcranial direct current stimulation (tDCS) is a clinical technique for a non – invasive stimulation by applying weak electrical current to the head that generates an electromagnetic field. This electromagnetic field modulates the activity of brain neurons modifying the neuronal trans - membrane potentials, thereby selectively influencing the level of excitability and modulating firing rates. Tests on healthy adults demonstrated that tDCS can increase cognitive performance on a variety of tasks, depending on the area of the brain being stimulated. tDCS has been also utilized to enhance language and mathematical ability, attention span, problem solving, memory, and coordination [Sparing and Mottaghy, 2008]. Each device has an anodal electrode and a cathodal electrode. The anodal electrode is the positively charged electrode and the cathodal electrode is the negatively charged electrode. The current flows from the cathodal electrode to the anodal electrode, creating a circuit. The device that delivers the current controls the current as well as the duration of stimulation [Utz et al., 2010]. One of the electrodes is placed over the region of interest and the other electrode, the reference electrode, is placed in another location in order to complete the circuit. This reference electrode is usually placed on the neck or shoulder of the opposite side of the body than the region of interest. Many devices have a built-in capability that allows the current to be "ramped up" or increased slowly until the necessary current is reached. This decreases the amount of stimulation effects felt by the person receiving the tDCS. After the stimulation has been started, the current will continue for the amount of time set on the device and then will automatically be shut-off. There are three different types of stimulation: anodal, cathodal and sham. The anodal stimulation is positive stimulation that increases the neuronal excitability of the area being stimulated. Cathodal stimulation decreases the neuronal excitability of the area being stimulated. Cathodal stimulation would decrease the neuronal excitability to reach a more stable level of activity [Nitsche et al., 2003]. Sham stimulation is important because it is the control stimulation. This stimulation emits a brief current but then remains off for the remainder of the stimulation time. With sham stimulation, the person receiving the tDCS does not know that they are not receiving prolonged stimulation; this provides a control condition for experiments, which can be double-blinded. Without this type of stimulation, the effects of the positive or negative stimulation could not be proven.

1.2. Flight simulation

The flight simulations with the experimental subjects in the Lab consisted in commercial flights departing from Pisa airport to Bologna airport by using the program *Microsoft Flight Simulator X*. During the flight simulations was possible to ask the subjects to perform also a secondary task, the task of alert and vigilance (TAV), from the end of the take off to the beginning of the landing for a total time of 30 minutes. Figure 1 shows a subject in the Lab facing the FS (central screen) and the TAV (left screen).

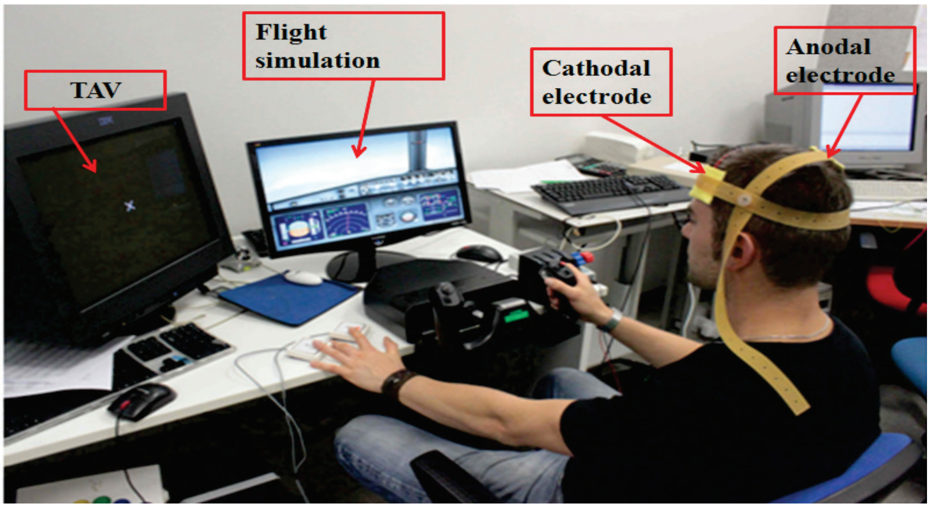

Figure 1. *From the climbing after the takeoff to the beginning of the landing the subject has to pilot the aircraft (central screen) and to perform the TAV (left screen).*

At the end of each flight simulation the subjects filled the NASA – TLX questionnaire [Hart and Staveland, 1988] in order to obtain subjective evaluation of the perceived workload during the experiments.

1.3. Task of alert and vigilance

The tasks of alert and vigilance (TAV) were the secondary tasks to pay attention at, while the subject was performing the FS. Except for the take off and the landing, during the entire FS the subject was engaged in the execution of the TAV.

Alert task

The task consisted in pressing a button every time an “X” was shown on the screen. Since the target was presented on the screen, the subject had 1500 [msec] for pressing the correct button (button number 2) as soon as possible, and the possible reaction times should be “Anticipation”, “Correct”, “Late” and “Omission”. Anticipation means that the subject pressed the button before the presentation of the stimulus plus a Δ time estimated around 350 – 500 [msec]. Correct corresponds to a reaction in the time interval from the presentation of the “X” to 1500 [msec] after it, otherwise the answer was classified as Late and, if the reaction time exceed 2000 [msec], it will be classified as Omission; in case of “not correct answer” in the log performance file there will be -1, -2 or -3, respectively, or 0 in case of “correct answer”. In figure 2 are shown the time definitions of the different kinds of answer.

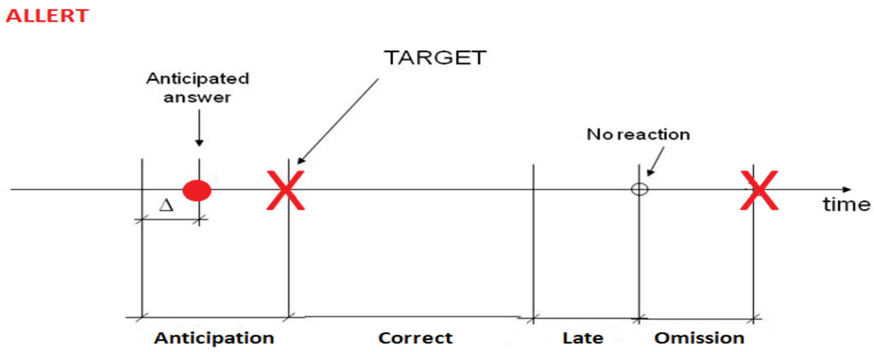

Figure 2. *Allert task. The TARGET is the stimulus shown on the screen and the subject should answer to it with different reaction times: early, correctly, lately or none answer.*

Vigilance task

At the same time the subject had to face the vigilance task that was the identification of the same acoustical frequency of consecutive tone impulses by pressing the corresponding button (button number 1). The goal of the vigilance task was to answer before the next tone impulse once identified the target sequence and in term of time window, the inter-stimulus time was of 2000 [msec] thus a response after this time interval will be named as Late, as Omission if there are no answers and as Error if the response will occur when the tone impulses are different. In figure 3 is shown an example of a tone sequence and the different types of errors of reaction.

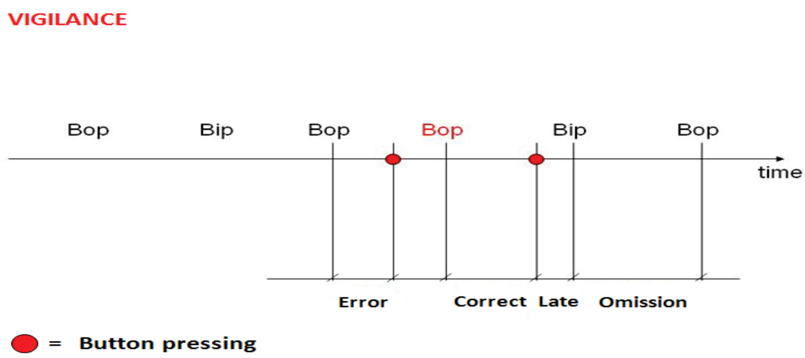

Figure 3. *Vigilance task. The target is the identification of the same tone impulse during the sound sequence and only after the second identical tone the subject has to answer by pressing the correct button. If the response is not appropriate, there are different kinds of error: early, lately or none answer.*

2. Material and Methods

2.1. Subjects

The subjects for the experiments in the Lab were selected by their ages and videogame skills. They were volunteers and experimental instructions were provided during the meeting before the experiment sessions.

2.2. Stimulation type

The subjects in the Lab were comfortably seated on a reclining chair, in an electrically-shielded, dimly-lit room. The tDCS stimulation was applied by using a battery driven Eldith Programmable Direct Current Stimulator with a pair of surface-soaked sponge electrode (5 x 7 cm). A constant current of 2 mA was applied on the skin for the entire duration of the task, almost 30 min. In the current randomized, double-blind, sham-controlled study, two sessions were provided to investigate safety and efficacy of tDCS during the task in improving accuracy and reaction time in the subjects. By the literature it has been chosen to stimulate the right parietal lobe (P4) [Corbetta and Shulman, 2002]. The anode was placed on the right parietal lobe (the P4 of the extended International 10-20 system for EEG electrode placement) while the reference electrode was positioned over the contra-lateral fronto-polar cortex [Nitsche and Paulus, 2000][Sparing et al., 2008]. Overall, we used anodal stimulation of P4 (P4-A) and Sham stimulation (P4-S). For the sham stimulation, the electrodes were positioned exactly like the anodic stimulation but in this case the stimulator device turned off after 30 seconds.

2.3. Flight errors estimation

The flight errors estimation has been done by recording the angles of pitch and bank during the entire flight simulation every second, by using *SimConnect*. The flight instructions were to mantain a precise path with exact angles'values in each part of it. For example, for reaching the altitude of 4000 (m) the pitch angle had to be 10 and the bank angle had to be 0. Comparing the real value of the angles with the ideal ones, the mean square errors (mse) have been calculated for any flight phase by the formula:

$$MSE(H) = \frac{K}{N}\sqrt{\sum(\varphi\,(i) - \delta)} \tag{1}$$

where H is the *h-th* flight phase, N the total number of samples, K is a constan number for the graphical representation of the parameter, φ(i) is the angle's value in the *i-th* second and δ is the ideal value in the *h-th* flight phase. Hence, the mse represets the difference of the real upset of the airplane respect to the ideal one. Figure 4 shows an example of the ideal flight path (red line) and of a real flight path (blue line), where each phase is defined by specific pitch and bank angles.

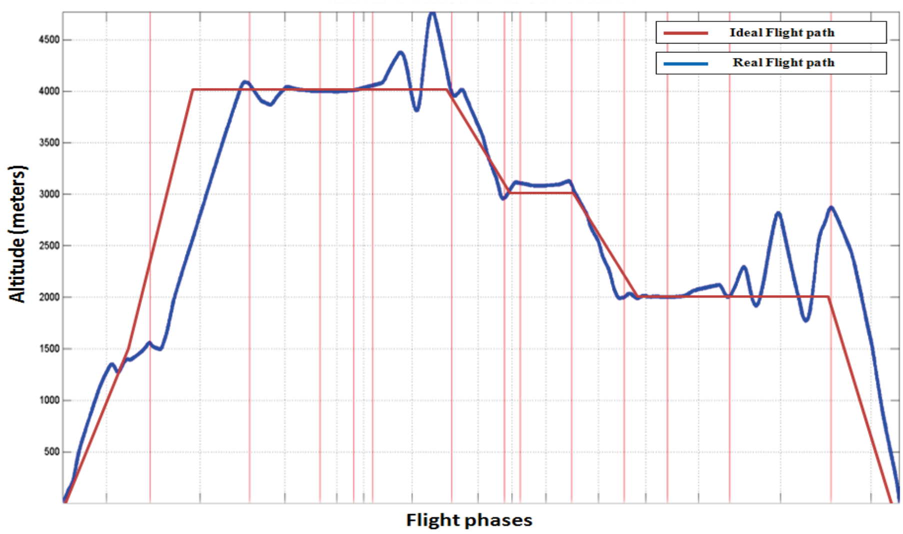

Figure 4. *The flight instructions indicate a precise path in each flight phase. By comparing the pitch and bank real angle's values(red line) to the ideal ones (blue line), the mean square errors were estimated.*

3. Results

3.1. Total performances

For a general performance evaluation, any single parameter has been transform in percentage and mean performance values have been calculated. These values contain information about the flight performance (how well the subjects followed the ideal path) by the pitch and bank mse and the TAV performance (how fast and correctly the subjects handle with the TAV tasks) by the reaction time and the error rate. The mean values of the two experimental conditions are represented in Figure 5. By comparing the rate of errors in the Sham condition (blue color) to the error rate in the tDCS condition (red color) the difference is evident. In fact, with the tDC stimulation, even if the subject did not know of the possibility of the 'fake' stimulation, the number of total errors decreases, hence, the performance increases. Statistical difference has been found for the bank mse ($p<0.03$).

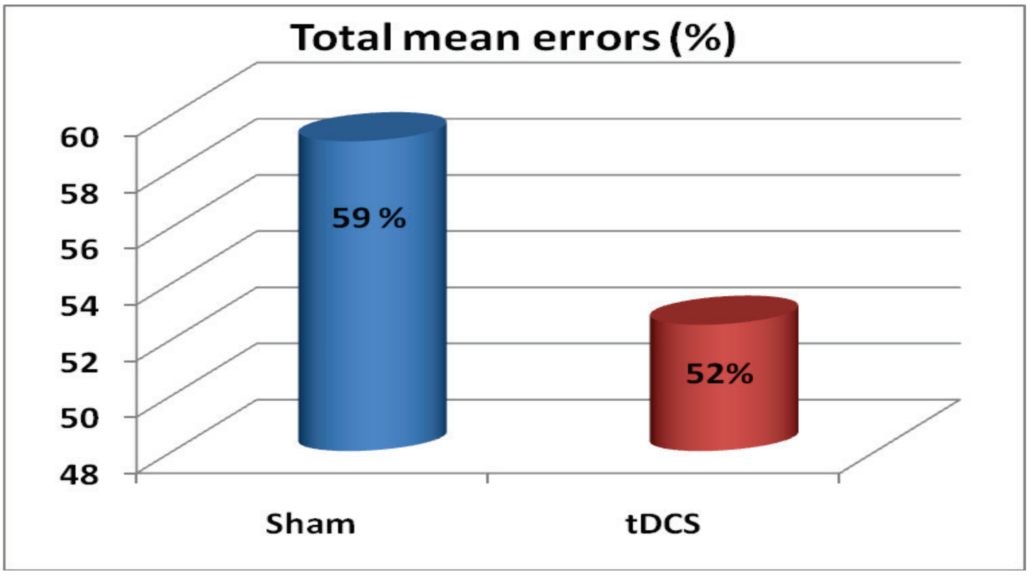

Figure 5. *Total mean error rates in terms of flight performance (mse pitch and bank) and TAV performance (reaction time and errors) of the two experimental conditions, with the tDCS stimulation (in red) and without stimulation (in blue).*

3.2. NASA - TLX

The same comparison was done for the score of the NASA – TLX questionnaire. As shows in Figure 6, also the total scores of the subjective workload evaluation are different in the two experimental conditions. Without knowing about the Sham condition, the subjects perceived a higher workload with no-stimulation than with the tDCS. These results support additionally the previous ones, in which the mean performance was higher during the tDCS condition than in the Sham condition.

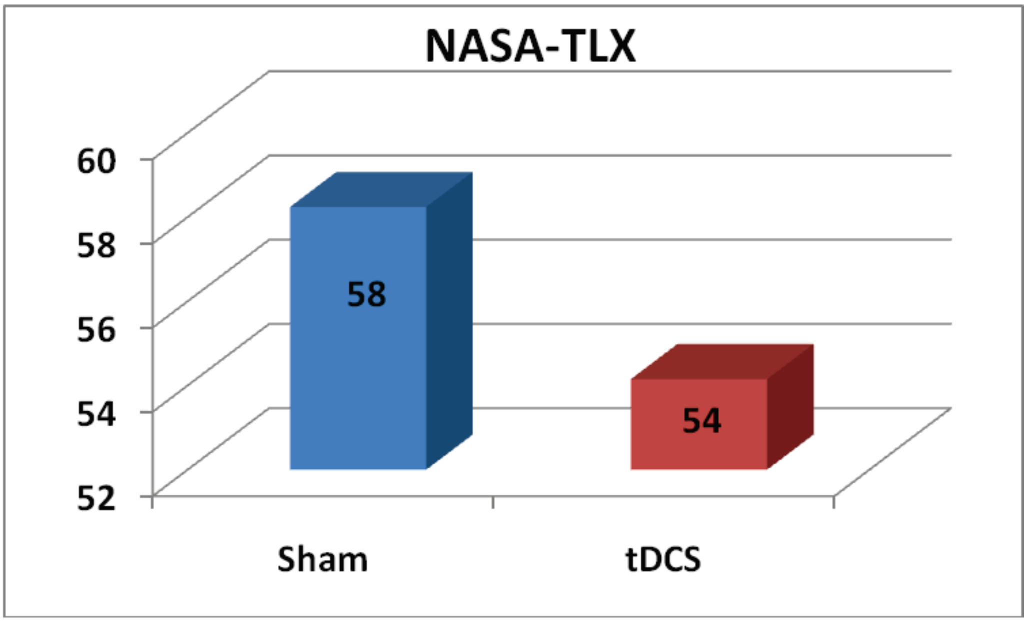

Figure 6. *Mean NASA – TLX total score of the two experimental conditions. It is possible to note how the value of the perceived workload with the tDCS stimulation (in red) is lower than without it (in blue).*

4. Discussion

In this paper, it has been demonstrated that it is possible to improve the performance while facing a task, for example a flight simulation, by using the transcranial direct current stimulation (tDCS). In fact, the results suggest that a global enhancement of the performance has been found when the subject receives the stimulation:

- Higher airplane upset control (mse anlges lower than in the Sham condition);
- Lower error in executing secondary tasks, the TAV, which could be thought to simulate radio answering or fuel system managing.

Even if these differences are not statistically different, from other studies [Borghini et al., 2011] [Borghini et al., 2012][Astolfi et al., 2012], in which also the brain activity has been recorded and analyzed, we found that the left and central frontal brain region are mainly involved during these kind of tasks.
Therefore, the next step will be experiments in which the stimulated brain site will be the left and the central ones.
This new stimulation choice will probably show statistical difference between the two conditions in terms of performance enhancement. We might conclude that the tDCS increases the performance in controlling the airplane while doing other tasks.

5. Conclusions

The results could suggest to stimulate professional pilots, military and commercial ones, before the flight, because the effects of the tDCS can last up to 5 hours after the stimulation and the final result could be a better information processing and system managing, hence improving the safety of the flight.

Acknowledgements

This study was the first part of *Brainshield*, a research project of Italian National Military Research (PNMR) in collaboration with the Administration of Difence, the IRCCS “Fondazione Santa Lucia”, the University Sapienza of Rome, the University of Palermo, the University Tor Vergata of Rome, the Centro Italiano Ricerche Aerospaziali (CIRA) and the University of Salerno. Brainshield’s partners are the Italian Airforce, Alitalia CAI, Alenia Aeronautica and Alenia Aermacchi. The project is funded by

the 5th Ward Segredifesa/DNA and the consortium has commissioned research by the Directorate General of Air Armaments.

References

Sparing R, Mottaghy FM. Noninvasive brain stimulation with transcranial magnetic or direct current stimulation – From insights into human memory to therapy of its dysfunction. *Methods*, 44: 329–337, 2008.

Utz KS, Dimova V, Oppenlander K, Kerkhoff G. Electrified minds: Transcranial direct current stimulation (tDCS) and Galvanic Vestibular Stimulation (GVS) as methods of non-invasive brain stimulation in neuropsychology-A review of current data and future implications. *Neuropsychologia*, 48(10): 2789–2810, 2010.

Nitsche MA, Nitsche MS, Klein CC, Tergau F, Rothwell JC, Paulus W. Level of action of cathodal DC polarization induced inhibition of the human motor cortex. Clinical Neurophysiology, 114: 600-604, 2003.

Hart SG, Staveland LE. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. Hancock PA & Meshkati N, eds. Human Mental Workload. Elsevier, 1988.

Corbetta M, Gordon LS. Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews*, 3: 201-214, 2002.

Nitsche MA, Paulus W. Excitability changes induced in the human motor cortex by weak transcranial direct current stimulation. *Journal of Physiology,* 527: 633–639, 2000.

Sparing R, Buelte D, Meister IG, Paus T, Fink GR Transcranial magnetic stimulation and the challenge of coil placement: a comparison of conventional and stereotaxic neuronavigational strategies. *Human Brain Mapping*, 29:82–96, 2008.

Borghini G, Isabella R, Vecchiato G, Toppi J, Astolfi L, Caltagirone C, Babiloni F. Brainshield: HREEG study of perceived pilot mental workload. *Italian journal of aerospace medicine*. 5: 34 – 47, 2011.

Borghini G, Isabella R, Vecchiato G, Toppi J, Astolfi L, Caltagirone C, Babiloni F. A flight history from a cognitive point of view: Novices versus Experts. *Italian journal of aerospace medicine*. 7: 46 – 59, 2012.

Astolfi L, Toppi J, Borghini G, Vecchiato G, He EJ, Roy A, Cincotti F, Salinari S, Mattia D, He B, Babiloni F. Cortical Activity and Functional Hyperconnectivity by Simultaneous EEG Recordings from Interacting Couples of Professional Pilots. In proceeding of the 34th International Conference of the IEEE/EMBC. 2012. In press.