



**UNDERSTANDING DUAL TASK PERFORMANCE IN HUMANS:  
ELECTROPHYSIOLOGICAL CORRELATES OF INTERFERENCES AND COSTS  
BETWEEN MOTOR AND WORKING MEMORY TASKS AT DIFFERENT LEVELS  
OF WORKLOAD**

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to obtain a degree of Ph.D. in Neurosciences

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## 2. LIST OF ABBREVIATIONS

C1 - cognitive task easy.

C2 - cognitive task medium.

C3 - cognitive task hard.

DT – dual task.

EEG – electroencephalography.

fMRI - functional magnetic resonance imaging.

Hz – Hertz (cycle per second).

ICA - independent component analysis.

MEG – magnetoencephalography.

MT – motor task.

M1 - motor task easy.

M2 - motor task medium.

M3 - motor task hard.

NaCl - sodium chloride

PET - Positron Emission Tomography

ROIs - regions of interest.

RT – reaction time.

S.E.M.: standard error

ST – single task.

TFRs - time–frequency representations.

WM – working memory.

### 3. ABSTRACT

The simultaneous execution of two different tasks is associated with interference processes that produce a decrease in the performance of one or both duties, a common phenomenon whose neural mechanisms are not yet understood. We recorded electroencephalographic activity (EEG) during cognitive-motor interference in 24 subjects, using a working memory N-back task concurrent with a finger movement both tests were performed on 3 different workloads (easy, medium and hard) resulting in 9 dual tasks of different difficulty levels. A time-frequency analysis of the EEG showed a midline decrease of theta band activity and an increase of alpha band activity when both tasks progressed to a motor workload medium level. The current study shows the development of an opposing oscillatory pattern of alpha and theta, which can be linked to the interferential effects of cognitive-motor task, determining the fall in the overall performance of the test. These effects are only a product of the increase in the difficulty of the motor task.

## 4. INTRODUCTION

### **Double task: the origin of the interference**

The performance of dual tasks (DT) has been a focus of interest for a long time due to the adverse effects on its execution compared to single tasks (ST), producing modifications in the optimal development of one or both tasks. This decrease in performance is related to an increase in cognitive load, demonstrating potential limitations of information processing that divide our attention (Pashler 1994). Among all the possible versions of a DT that elicit interference: a) Cognitive-cognitive (mainly applied to tasks of perception and working memory, for example color and shape of objects presented during a task), b) motor-motor (mainly applied in bimanual coordination or in tasks that involve movement of segments of the upper and lower limbs) and c) cognitive-motor (which usually combines working memory tasks with motor tasks such as human gait or standing). We focus here on cognitive-motor interference, where a standard motor activity occurs concurrently with a cognitive task.

The importance of the phenomenon of cognitive-motor interference is that every day people perform multiple tasks concurrently. Activities such as walking and driving while participating in a conversation, test the individual ability to attend

various actions, sometimes in competition, with shifts and distribution of attention to control movements safely. Therefore, Multitasking is ubiquitous in our everyday life.

The central nervous system's ability to process this information is limited (Marois and Ivanoff 2005), and it influences their capacity to prepare and perform tasks simultaneously. The question of why motor tasks lead to a cognitive performance decrement and vice versa is still discussed (Leone et al. 2017; Liebherr et al. 2018). A traditional view is that highly automated processes – like ordinary locomotion – do not take up attentional resources (Norman et al. 1986). Currently, several studies have shown that a common motor task such as walking, standing or moving a limb needs cognitive / attention resources to be performed, demonstrating that cognitive-motor interference processes arise depending on the level of difficulty imposed by both tasks (Liebherr et al. 2018; Papegait et al. 2017; Rémy et al. 2010), so not all DTs produce interference.

### **Behavioral approach to cognitive-motor interference.**

There are many behavioral studies on cognitive-motor DT, which support the existence of interferential processes during their execution, mainly associated with conditions and diseases that cause lower performance states during the performance of DT, among them we found multiple sclerosis (Leone et al. 2015; Prosperini et al. 2015; Wajda et al. 2016; Malcay et al. 2017), Parkinson's (Rochester et al. 2014; Hazamy et al. 2017; Whitfield and Goberman 2017), Stroke (Negahban et al. 2017; Timmermans et al. 2018) and the also called natural effects on aging

(Hall et al. 2011; Klotzbier and Schott 2017). These researches demonstrated a delay in reaction times (RTs) (Mishra et al. 2013; Hazamy et al. 2017), spatiotemporal changes in gait (Al-Yahya et al. 2011; Hall et al. 2011; Rochester et al. 2014; Timmermans et al. 2018) or alterations in postural control (Prosperini et al. 2015; Wajda et al. 2016; Negahban et al. 2017). For this purpose, many cognitive tests have been used, being the most common: mathematical calculations, numerical counting, or working memory tasks that involve remembering the position or characteristic of some object present in the visual field of people among others (Klotzbier and Schott 2017; Malcay et al. 2017; Timmermans et al. 2018). However, some studies show discrepancies in dual-tasking results, indicating improvements or a null effect on the behavioural parameters during the execution of the DT. Verrel et al. (2009) using the N-back tasks showed that gait patterns became more regular with increasing cognitive task. Kline et al, using a spatial working memory task (of high difficulty), demonstrated that there were no changes on gait speed when a simultaneous cognitive task was performed (even at different walking speeds) (Kline et al. 2014). These studies increase the body of available knowledge about DTs, but are limited in explaining the neural bases of the interferential processes in cognitive-motor DT.

### **Is the motor system independent of executive functions?**

All of these motor functions require the precise execution and constant adaptation of movements, elaborated coordination between visual perception and

processes of motor control. Therefore, it can be assumed that executive functions participate in the sequencing of any of these processes.

The motor system works through procedural memory that is considered as long-term memory, and its learning is based on constant repetition of movement patterns till all the motor systems coordinate to generate automatic and harmonic movements (Brem et al.,2013). Automatism is one of the main elements which highlight motor functions. It has the disadvantage that structures which participate in its functions are not easy to access using EEG, so the studies that have reported new findings within this field, have principally used neuroimaging methods. The main structures participating on the motor processes are the motor cortices (primary and supplementary), basal ganglia, cerebellum, nuclei of the brainstem and spinal cord (Purves, 2007). The latter, are responsible for automatic movements like gait, controlling its rhythm (Latash, 2008) and the cortico-spinal system (originated from the motor cortices, mainly from the primary motor) influences movement at all levels. The EEG has principally been employed to study neural oscillations during high-level cognitive tasks, and research efforts have been oriented to understand the role of brain oscillations in cognitive processes, with a particular interest in the theta and alpha frequency bands.

Marvel and Desmond (2010), presented relevant information about another structure that it is outside of the boundaries of EEG electrophysiological methods, this structure is the cerebellum, where cognitive and motor functions co-exist. On their review, they conclude that the phonologic loop of WM (where a process of

active rehearsal is made), is performed on the medial region of the anterior cerebellum, precisely in the same zone where finger movements are made.

Ikkai y Curtis (2011) in a review based on neuroimaging studies concluded that shared neural mechanisms exist, which are common to the processes of WM (spatial), attention and movement intention. The prefrontal and posterior parietal cortices would take part in the memory circuit, participating actively in a wide range of cognitive processes (motor planning, localization, and attention, among others). Brem et al. well describe the interactions between both systems. “Notably, motor learning and motor memory has been regarded as a less cognitive form of memory functions, and most research makes a clear distinction between motor and nonmotor memory functions. Thus, it seems clear that memory processes are interactive and partly overlapping domains” (Brem et al. 2013). In this context, it becomes clear how WM has been widely used in the research of memory, attention, and high-level cognitive functions in general.

### **WM as a doorway to the neural bases of interference.**

Several studies from a neural perspective have explored the representation of the interferential mechanisms during DT in cognitive-motor tasks. Research efforts have been oriented to understand the role of brain oscillations in cognitive processes, with a particular interest in the theta and alpha frequency bands. Researchers have employed EEG to study neural oscillations during high-level cognitive tasks, such as working memory (WM). WM is the temporal retention and

handling of goal-relevant information through persistent brain activity (Baddeley 2000; Soreq et al. 2019). The two main features of WM are the short term retention (few seconds) and the limited capacity (2 to 7 items) to retain information (Baddeley and Hitch 1974; Goldman-Rakic 1995). Based on neurophysiological studies in primates, Goldman-Rakic, and colleagues defined WM as the ability to hold an item of information transiently in mind, in the absence of external stimulation (Goldman-Rakic 1995). The brain regions actively involved in WM encoding, maintenance, and retrieval are the intraparietal sulcus (Luck and Vogel 1997; Scheeringa et al. 2009), the frontal eye-field (Xu and Chun 2009), and the dorsolateral prefrontal cortex (Courtney et al. 1998; Funahashi 2006; Zhao and Ku 2018).

Several tests have been used to assess different components of WM, but during the last years, the N-back test has been the most used to analyze the basic interactions of the WM process (Owen et al. 2005). On this task, the subjects have to identify if the actual stimulus (number or letters) of successive tests is the same that was presented in n previous tests. During the execution of the WM task, the stimuli have to be continuously updated in order to keep the focus on the task (Palomäki et al., 2012). The cognitive load factor n can vary (1-, 2- o 3-back) to make the task more or less difficult, thus varying the cerebral activity of the subjects (Pesonen et al., 2007). Some studies also use the 0-back factor, but this is not considered as a WM task since it does not exist any retention of information (Owen et al., 2005).

The variation of the cognitive load factor, is one of the most studied elements of WM. Neuroimaging studies have indicated the zones which present greater changes during execution of tasks with different WM. Owen et al. (2005), analyzed various studies that used fMRI and n-back task, showing that different cortex activity is associated to their functions: medial and lateral premotor, anterior cingulate (Dorsal), ventrolateral prefrontal and dorsolateral, frontal pole, medial posterior parietal, inferior parietal lobule, medial and lateral cerebellum and the thalamus, showing that these cortical zones were more active when the content of the memory task was from verbal nature (letters) rather than non-verbal (numbers or images).

In this context, it should be noted that while functional Magnetic Resonance Imaging (fMRI) and Positron Emission Tomography (PET) have successfully linked brain regions to task modality specific WM processes (Roffman et al. 2016; Soreq et al. 2019), electrophysiological techniques are better suited to understand the rapid temporal dynamics of some of the underlying neural mechanisms (Jensen et al. 2002; Crespo-Garcia et al. 2013; Cavanagh and Frank 2014).

In human EEG and magnetoencephalography (MEG), the maintenance of visual information in WM is associated with amplitude modulations of specific frequency bands (Moran et al. 2010). More specifically, it has been shown that amplitude increases in alpha (8-12 Hz) (Jensen et al. 2002; Klimesch 2012) and theta (4-8 Hz) bands increasing in direct dependence of memory load (Jensen and Tesche 2002; Sauseng et al. 2005; Klimesch et al. 2006; Cavanagh and Frank 2014). Theta band has been associated with increases in cognitive load, presenting an increase in frontal electrodes of the medial line (Gevins et al. 1998; Mitchell et al.

2008; Popov et al. 2018). Intracranial EEG recordings have also reported evidence of theta oscillations modulation in the middle frontal gyrus during a WM task (Raghavachari et al. 2001). The function of theta-band activity seems to be associated with the encoding and recovery of information, reflecting sustained cognitive processing (Krause et al. 2000; Pesonen et al. 2007). Also, theta-band activity has been associated with specific functions of the central executive (Sauseng et al. 2005), probably reflecting communication between areas featuring a fronto-central hub (Onton et al. 2005; Nigbur et al. 2011) and the maintenance of sustained attention in memory processes (Mitchell et al. 2008). It has also been suggested that the theta band is a marker for cognitive interference during perceptual processes (Nigbur et al. 2011).

Alongside theta band changes, some authors also have found modulations of the alpha band. Pesonen et al. showed changes in alpha during N-back tests (0, 1, 2, and 3-back), reporting an increase in alpha as the difficulty of the task was increased, presenting the highest activity when the target stimulus was presented (Pesonen et al. 2007).

The interrelationship between both frequency bands (alpha and theta) probably reflects the cognitive state of execution and memory processes, even though alpha desynchronization is associated to neural inhibition of task-irrelevant channels as cognitive load increases (Klimesch 1999, 2012; Jensen et al. 2002; Crespo-Garcia et al. 2013). Krause et al. reported of brain oscillatory responses of the 4–12 Hz EEG frequencies during a visual n-back task utilizing the 0-, 1- and 2-

back memory load conditions. Their results reported an increase in theta (4-6 Hz) and a decrease in alpha (8-12 Hz) as the complexity of the task increased.

### **Correlates of dual task interference.**

Several studies have explored the neural representation of the interferential mechanisms during DT in cognitive-motor tasks, demonstrating changes in different brain regions when the demands of the tasks performed increased. fMRI studies have shown changes of over-additive in the prefrontal and parietal cortex (Van Impe, Coxon et al., 2011, Wu, Liu et al., 2013) among which the supplementary motor area is the most involved (Van Impe, Coxon et al., 2011). This result supports the idea that increases in difficulty in both tasks require greater activation of the areas involved (Holtzer et al. 2011) being reported even cerebellar areas involved in the sequencing of tasks while the subjects performed the fingers tapping and letter counting tasks simultaneously (Wu, Liu et al., 2013). However, other studies found only additive activation of both tasks involving only the specific cortical areas of each simple task (Anderson et al. 2011) or under-additive activation of DT performance. Example of this last condition is the work of Johansen et al. he addressed the dual-task paradigm through neuroimaging techniques (fMRI) and a cognitive-motor test: The WM N-back with different cognitive loads (0 and 2-back) plus the execution of a rhythmic motor task with the feet, simulating human gait (movements associated with an audible signal). Their results showed that the main differences in the activation occurred in the inferior frontal gyrus and the superior parietal lobe

producing less activation of these areas with increasing cognitive load and motor tasks (Johannsen et al. 2013). Discrepant results that give rise to many theories about the control processes and their possible limitations.

Changes in the prefrontal cortex have been shown when performing a walking while talking compared with normal walking. These changes were even greater in younger subjects compared to older adults, suggesting that older adults under-utilize the prefrontal cortex in attention demanding locomotion tasks (Holtzer et al. 2011). Rosso et al. found very different results. Using a task of postural control and attentional reaction, they demonstrated that the total activation of the left motor, temporal, and dorsal-lateral prefrontal cortex was less than expected than the sum of individual conditions for younger and older adults. It is suggesting that the interference between both tasks was represented by a decrease in cortical activation (Rosso et al. 2017). These reports support the hypothesis of constant interference between both processes, motor and cognitive, when simultaneously executed. However, there are limited studies that address this problem through electrophysiological parameters (Leone et al. 2017). Bohle et al. 2019 report changes in theta band when comparing a population of young people versus older adults. The tasks included a single postural task, a cognitive-postural dual task, and a cognitive-postural triple task (cognitive dual-task with postural demands). Their participants performed a one-back (low cognitive task demand) or a two-back working memory task (high cognitive task demand) and stood on a fixed (low postural task demand) or a free-swinging platform (high postural task demand). They found higher alpha frequency synchronization for increasing dual-tasking difficulty in

young and a decrease in midline theta (higher in older adults) as tasks increase in complexity. A recent research by Reiser et al. used EEG-mobile to know the changes resulting from cognitive-motor interference in outdoor environments in the real world (ecological approach). The participants performed an auditory oddball task while concurrently completing various motor tasks with three difficulty levels (standing, walk and walk between obstacles). Their results indicate that decrease frontal midline Theta power with higher motor load. The authors propose that increased movement complexity imposes a higher workload to the cognitive system, which, in turn, effectively reduces the availability of cognitive resources for the cognitive task. This is one of the few reports that propose the sequential progression of the difficulty of the motor task as an interference variable.

In current literature, many works only report changes on the cognitive load without taking into consideration the increased difficulty of the motor task. Therefore, those studies only address the cognitive level but not the possible influence of the motor processes, although the motor system is necessary for our daily lives (as it allows us to interact with the environment), it is generally considered only as a response system in psychology and neuroscience studies. Perhaps this is because neuroscience has focused on understanding the neural basis of cognitive processes (perception, attention, language, etc), more than sensorimotor processes (Latash, 2008). Neuroimaging studies (fMRI) present evidence about cognitive and motor shared structures, which are related to processes associated with WM and motor planning (supplementary motor area and superior parietal lobe), but contradictory results have given rise to many theoretical discussions about the control processes

involved (Rémy et al. 2010; Van Impe et al. 2011; Johannsen et al. 2013). A critical limitation in those fMRI studies lies in its poor temporal resolution, making them unable to identify modulations of the electrical neural activity that could lead to the understanding of cognitive-motor interferential processes. Due to the poor temporal resolution of fMRI studies, we decided to explore oscillatory modulations with EEG of cognitive-motor interferential processes in a dual cognitive-motor task.

According to the literature discussed above, we therefore hypothesize that increased movement complexity will also lead to a decrease in the number of cognitive resources that may be expended for the cognitive task. As a consequence, fewer attentional resources should be directed towards the cognitive task when the motor task demands are high. We expect the Theta band decrease their power as the complexity of the motor task increases. Theta changes will be the product of the limited attention resources available for the cognitive task. As a result of these changes, alpha should increase due to functional inhibition during the test. Besides, we expect a decrease in behavioral performance in conditions of the high complexity of movement compared to low due to cognitive-motor interference.

## 5. HYPOTHESIS

### General

The interference of cognitive-motor dual tasks be represented in modulations of frontoparietal theta that decreases his power by the process of division of attention and management of the volume of information when the motor task increases in complexity.

### Specifics

1. Increased difficulty of a motor workload also produces effects in electrophysiological modulation of Alpha due to functional inhibition during the test, when both tasks (cognitive-motor) are executed simultaneously.
2. The onset of cognitive-motor interference is marked by a significant decrease in behavioral performance and it occurs simultaneously with the modulation of theta frontoparietal and alpha occipital.
- 3.- The effects of cognitive-motor interference occur only when a high motor workload and a high cognitive workload are combined.

## **6.OBJECTIVES**

### **General**

Determine if cognitive-motor interference from dual tasks is represented by the decrease in the power of frontoparietal theta when the motor task increases in complexity.

### **Specifics**

- 1.- Determine if the increase in the complexity of the motor task while executing a dual task can produce a decrease in the power of Alpha.
- 2.- Identify if the begin of the process of cognitive-motor interference is associated with both decreased behavioral performance as modulation of Alpha and Theta band.
- 3.- Analyze if the effects of cognitive-motor interference only occur when a high complexity motor task and a high cognitive task (higher workload) are associated.

## **7. MATERIALS AND METHODS**

### **Methods**

#### **7.1 Participants**

Twenty four healthy volunteers (mean age = 22.9 years, SD = 2.37, range 18–26 years) participated in this study. All participants had normal or corrected-to-normal vision and reported neither current nor past neurological or psychological conditions. To minimize the effect of hemispheric biases, only right-handed subjects were recruited. All participants performed the experiment in the morning. Participants were informed of experimental conditions and gave written consent prior to initiating the testing sessions. All procedures were approved by the ethics committee of the Pontificia Universidad Católica de Chile.

#### **7.2 Experimental procedures**

The experimental procedure consisted of performing DT cognitive-motor, combining the different levels of workload between them, in order to progressively evaluate the effects of interference.

### **7.3 Cognitive Task**

We used the working memory task n-back. During the N-back task, the subjects are presented with a series of items appearing on a screen one at a time. They are asked to decide whether each item in the sequence matches the one that was presented n-items ago (Figure 1A). In our study, we used the three levels of n-back to regulate cognitive workload: 1-Back (easy level – C1), 2-Back (medium level – C2), and 3-Back (hard level – C3) (Figure 2A). In letter version of this task, the participants had to decide whether a letter currently presented on the screen is the same as the one presented n letters earlier. The used test set consisted of 5 letters, namely B, D, F, G, and H. Vowels were not included to prevent semantic associations. Each letter was presented on the computer screen for 1000 ms. A fixation cross appeared on the screen between trials (a letter presentation) for 1000 ms. Each time a new letter was presented, it was accompanied by an auditory signal of 50 ms and 40 dB which marked the beginning of each test. The participants had to answer verbally on a microphone in front of him. The verbal response was "yes" when the letter was the same as the one n letters ago and "no" when the letter was not the same as the one n letters ago.

### **7.4 Motor Task**

The motor task was a finger tapping movement on a keypad. The task was performed with the right hand with three workloads: one finger taps (index finger movement – easy level – M1), two fingers tap (index and middle fingers movement

– medium level – M2) and three fingers tap (index, middle and ring fingers – hard level - M3) (Figure 2B ). In every attempt, the movement of finger tapping starts with the index finger and moves towards the ring finger. The motor performance was executed after the appearance of the auditory signal that started each trial.

## **7.5 Dual tasks**

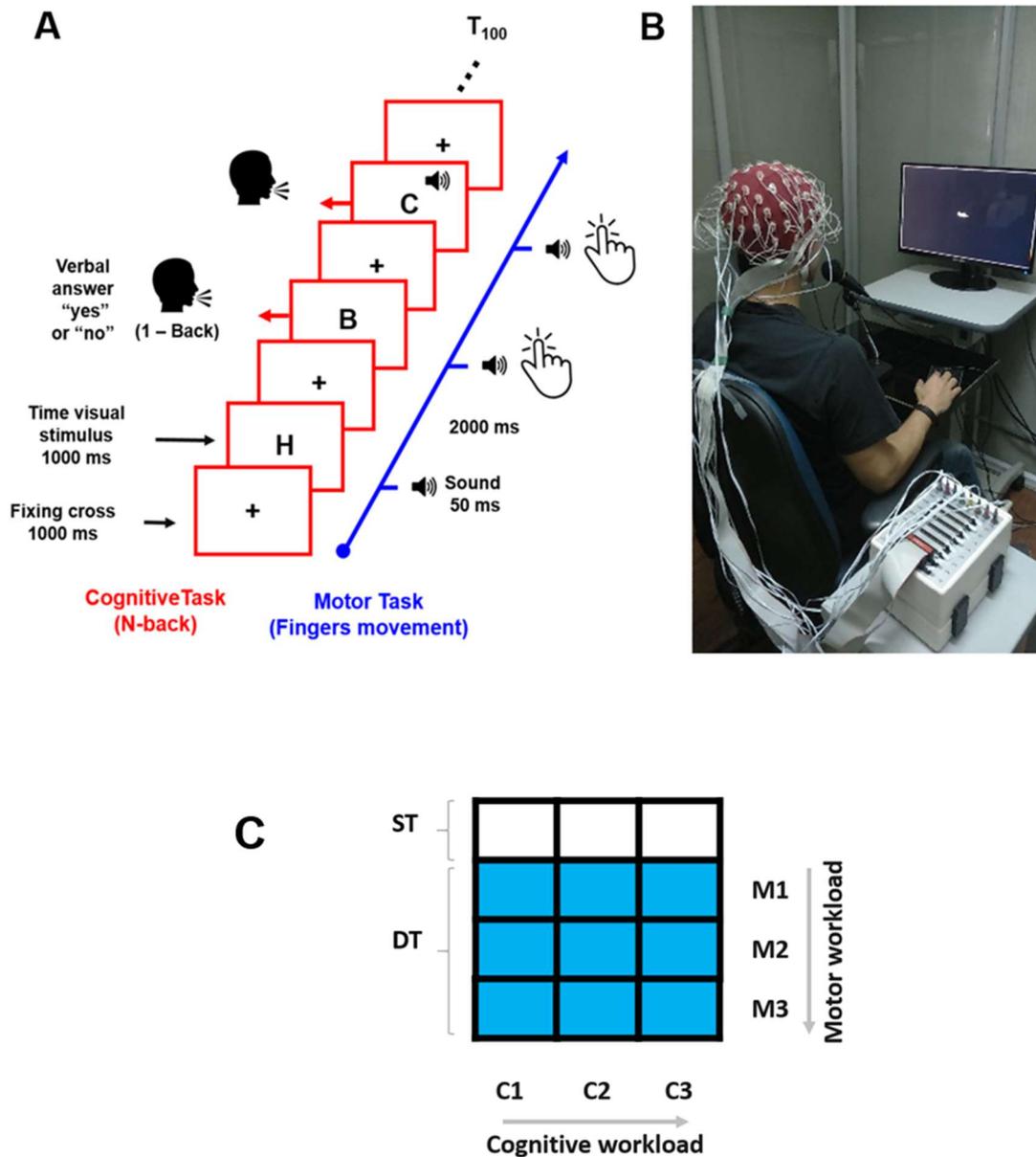
Participants were seated in a sound-attenuated and dark experimental room at a distance of 70 cm from a 17-inch monitor (ViewSonic, display dimensions 330×240 mm, resolution 800×600 pixels, vertical refresh rate of 100 Hz).

Participants placed both arms on the chair's arms, and the right hand was placed on a keypad to generate the movements of the fingers for the motor tasks. A microphone was placed in front of the subject for the verbal responses of the cognitive tasks (Figure 1B).

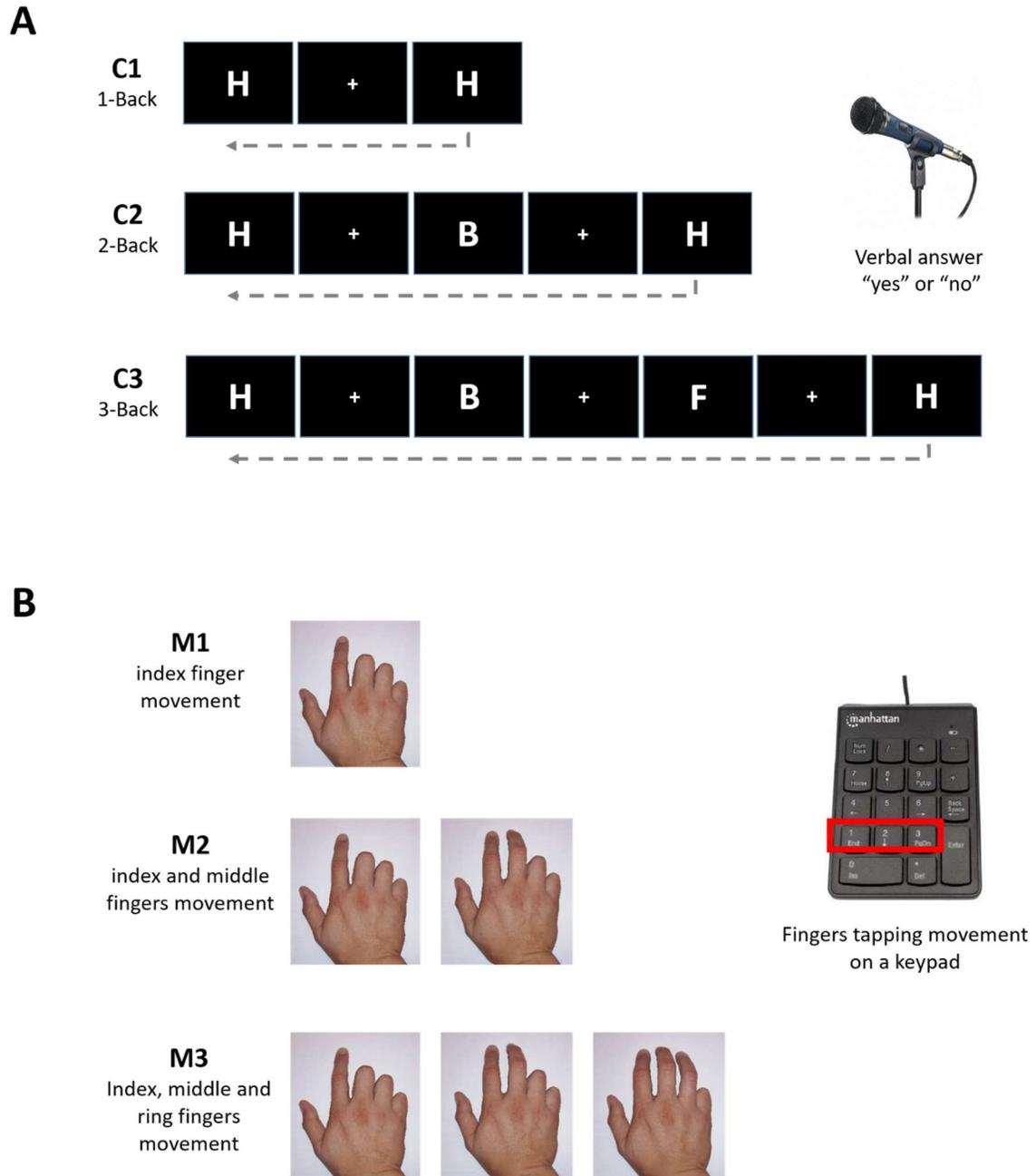
The EEG data were recorded in a room with shielding of electromagnetic interference. To evaluate the levels of cognitive-motor interference, a grid that combined all possible combinations of the workload of both tests was generated. Resulting in 9 dual tests (Figure 1C). In addition, three single tests were performed, which were used only as a baseline level of performance for cognitive and motor tasks. In total each subject had to perform 15 tests of 100 trials each. The order of execution of the tests was carried out randomly, being drawn the same day that the subject performed the tests in order to avoid a progressive learning effect. Between tests, the subject rested 4 min and every five tests had a rest of 10 min. Subjects

were asked to respond to all tests as quickly and as accurately as possible. Before dual tasks, the subjects were allowed to develop their own response sequence without asking them to have a preference or prioritize one of the two tasks over the other.

All subjects were familiarized with the single task during an initial training session 48 hours before the experiment to ensure that the subject understood the test. They practiced the tasks until achieved a minimum 75% correct response accuracy on three levels on cognitive task and motor task and thus eliminated a learning effect during data collection.



**Figure 1.** Experimental paradigm. **A)** Dual task experimental paradigm. **B)** Shows the experimental setup. **C)** Experimental design of the different motor and cognitive workloads that participants must perform. **ST:** single task; **DT:** dual task; **C1:** cognitive task easy; **C2:** cognitive task medium; **C3:** cognitive task hard; **M1:** motor task easy; **M2:** motor task medium; **M3:** motor task hard.



**Figure 2.** Workloads of cognitive and motor tasks. **A)** Cognitive tasks. **B)** Motor tasks.

## **7.6 Signal acquisition**

EEG brain activity data were acquired at 1024 Hz from 64 BioSemi ActiveTwo electrodes (BioSemi, Amsterdam, Netherlands) placed according to the international 10–20 system and two reference electrodes were placed on both mastoid bones. EEG signals were filtered using a 0.01–100 Hz band-pass. The impedance between the electrodes and scalp was under 10 k $\Omega$  with a NaCl-based conductive gel. During the breaks in the EEG session, electrode impedance levels were checked and reduced if necessary.

The task was administered using Presentation software (Version 18.0, Neurobehavioral Systems, Inc., Berkeley, CA). The behavioral data, include the reaction time (RT) motor (movement index finger on a keypad) and RT cognitive (verbal response into a microphone in front of the subject). The total duration of the experiment was around 120 minutes, including 30 minutes for the initial setup of the equipment, introduction of the subjects, and informed consent signing. It is important to note that ten subjects were discarded from the analyzes performed in the following section, because they did not perform the nine conditions of DT of the initial model.

## **7.7 Behavioral Analysis and Statistics**

The main behavioral variables collected in all trials were the following: percentages of correct answers (performance), RT of cognitive and motor tasks and motor sequence time (coordination between fingers). Incorrect trials were excluded from all analyses. Mean RTs and motor sequence time were analyzed with the Friedman

test and Dunn's post-hoc multiple comparisons between all conditions ( $p < 0.05$ ), contrasting the effects of increases in workloads for tasks (cognitive task in relation to the increase of the motor workload). Statistical analyzes were performed with GraphPad Prism v8 (GraphPad Software, San Diego, California USA).

## **7.8 EEG Preprocessing**

EEG data preprocessing was performed in MATLAB (R2015b, The MathWorks, Inc.) with EEGLAB (Delorme and Makeig 2004). The recorded EEG signals were band-pass filtered from 1 to 30 Hz and re-sampled to 512 Hz. Epochs were created from 500 ms before to 1500 ms after the stimulus onset. The time period of -500 to 0 ms was used as baseline. Missed responses were classified as incorrect trials and only correct trials were selected for further analysis. Independent component analysis (ICA) was performed to remove the artifacts caused by eye blinks, eye movement or other types of noise from the signal. For the analysis of cortical oscillations, five regions of interest (ROIs) were used (based in Palomäki et al. 2012): Fp1, Fp2, AF3, AF4, F3, F1, Fz, F2, F4, FC3, FC1, FCz, FC2 and FC4 (frontal), F7, F5, FT7, FC5, T7, C5, TP7, CP5 and P7 (left temporal), F8, F6, FC6, FT8, C6, T8, CP6, TP8 and P8 (right temporal), C3, C1, Cz, C2, C4, CP3, CP1, CPz, CP2 and CP4 (parietal), and P5, P3, P1, Pz, P2, P4, PO3, POz, PO4, O1, Oz and O2 (occipital location).

## **7.9 EEG frequency analysis and Statistics**

To extract the frequency characteristics of the EEG signal, we used the filter-Hilbert method. This method allows the extraction of time-series estimates of power by obtaining the analytical signal (Cohen 2014). To bandpass-filter the data in 1 Hz frequency bins from 1 to 20 Hz, we used the EEGLAB function `pop_eegfiltnew` set to default. This function uses a Hamming windowed sinc FIR filter, and the filter order with our data sampling rate is set automatically to 1690. Thus, we have a high order filter with a sharp transition between the frequencies being passed and those being stopped.

Then, to obtain the analytic signal, we used the `hilbert` MATLAB function in each frequency bin. This function computes the Fast Fourier Transform (fft) on the signal, and then it doubles the positive-frequency Fourier coefficients and zeros the negative-frequency Fourier coefficients. This step is equal to rotating the positive-frequency components one-quarter cycle ( $-90^\circ$ ) counterclockwise and the negative-frequency components one-quarter cycle clockwise ( $90^\circ$ ) in order to extract the power and phase of the signal (Cohen 2014). Then, the Inverse Fast Fourier Transform is computed on the modulated Fourier coefficients (Cohen 2014). Finally, the length of the complex vector (complex magnitude) was extracted using the MATLAB function `abs`. This resulted in a 4-dimension matrix of frequencies by channels by time points by trials.

The data was then baseline normalized using a z-score where the signal at each time point is subtracted by the mean power of the baseline and divided by the power standard deviation of the baseline (-500 to 0 ms). To obtain frequency band-specific power, we averaged the frequency bins for the theta (3-7 Hz) and alpha (8-12 Hz)

bands. The temporal profiles of theta and alpha were compared between tasks using a Wilcoxon signed-rank test of non-overlapping 50 ms windows during the post-stimulus period (0 to 1500 ms). The p-values obtained were corrected for multiple comparisons using the false discovery rate function (fdr) of EEGLAB.

To further analyze the temporal dynamics of theta and alpha, we extracted the mean power of theta and alpha bands in two-time windows of interest using the Hilbert Transform. The early phase was from 0 to 650 ms, and the late phase from 650 to 1300 ms post-stimulus. Once the values were obtained, the average of each subject in each test was used to represent the changes in the theta and alpha bands during the different conditions. The data was analyzed with the Friedman test and Dunn's post-hoc multiple comparisons for theta and alpha in different conditions ( $p < 0.05$ ). Statistical analyzes were performed with GraphPad Prism v8 (GraphPad Software, San Diego, California USA).

## 8. RESULTS

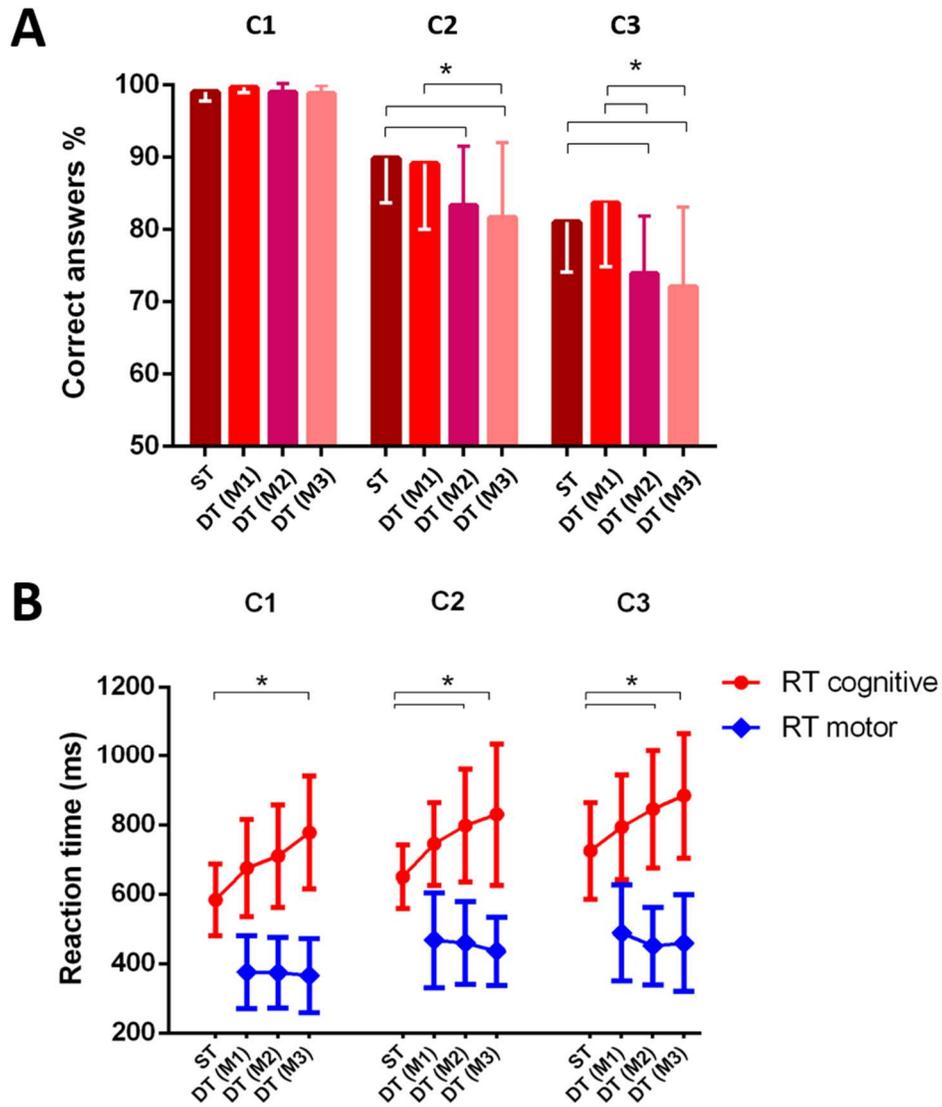
### 8.1 Behavioral outcomes

In order to verify that the key behavioral markers of the CT were reproduced, we calculated the mean of the performance and RTs only for ST. The results show significant differences between ST levels for performance (Figure 3A). The performance drop and the RTs increase were associated only with the increase in difficulty of the CT results, consistent with previous reports (Palomäki et al. 2012; Imperatori et al. 2013). The behavioral results show that when the C1 is executed in a ST or associated with a DT its performance is always close to 100%. Therefore there is no significant effect associated with the incorporation of the second task. Thus, regardless of the motor workload, the performance remains constant. Significant effects on DT performance are observed when combining medium or hard CT workloads with M2 and M3 workloads, demonstrating that the incorporation of a more complex MT causes a drop-in performance of DT (Figure 3A).

Cognitive RTs show a progressive increase in response latency when increasing the motor workload, presenting significant differences in all levels of cognitive workload (Figure 3B). These results show that in the DT, as the workload of the MT increases, the RTs of CT are slower and late than those made in the previous workload, presenting significant differences in the DT levels with workload of M2 and M3. In motor RTs, there are no changes within each cognitive level. Moreover, these results

demonstrate the existence of a DT execution strategy, in which the subjects prioritize the execution of the MT before the CT. This strategy arises innately since an order of preference was not indicated to the subjects to perform the dual tasks.

In addition to the variables named above, it was also considered the motor sequence time (coordination between fingers) that represents the time it took to perform the sequence of the fingers. It was only considered for motor workload M2 and M3. No changes were observed in motor sequence times when performed with different levels of cognitive workload in DT. These results indicate that motor sequence time was not influenced by DT (see annex 1).

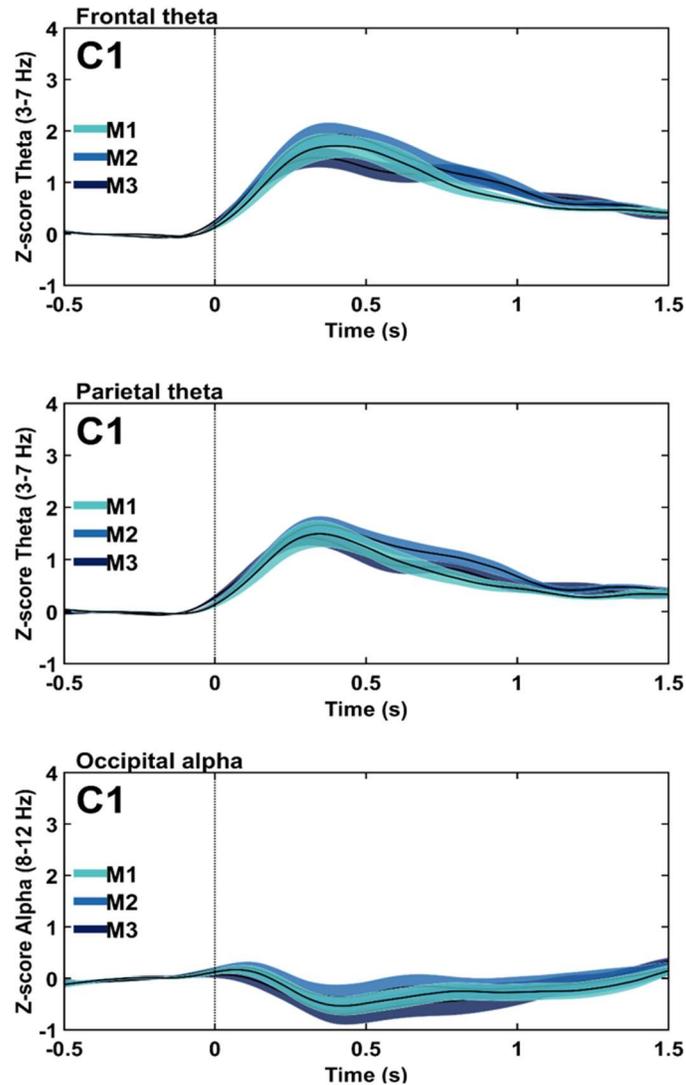


**Figure 3.** Behavioral results. **A)** Performance (percentage of correct answers) in the cognitive task through the different motor workloads (red scale). **B)** Reaction times (ms) of the same cognitive (red) and motor tasks (blue). The data were analyzed with the Friedman test and Dunn's post-hoc multiple comparisons ( $p < 0.05$ ). The asterisk represents the significant differences between the different levels of workload (see annexes 2,3 & 4: tables with the p values for each comparison). The results show that as the motor workload is increased, there is a drop in the performance (C2 and C3) and an increase in the cognitive reaction time (C1, C2 and C3). **ST:** single task; **DT:** dual task; **C1:** cognitive task easy; **C2:** cognitive task medium; **C3:** cognitive task hard; **M1:** motor task easy; **M2:** motor task medium; **M3:** motor task hard. Error bars = S.E.M.

## **8.2 EEG OUTCOMES**

### **8.2.1 Dual tasks: C1 vs. all level of motor workload**

When the subjects performed the easy C1 alone, there is an increase in the theta band associated with the difficulty level of the task (data reported in Annex 8, Figure 8.1). When progressing to DT with different levels of workload, the pattern of cortical oscillations remains very similar. The alpha band has no changes at all workload levels. Statistical comparisons between the different conditions time-series showed no significant changes (Figure 4). The power of brain oscillations are presented in Figure 7 (at the top), it is possible to observe that theta band (early and late) is increased, while the power of alpha (early and late) is diminished. No significant differences were found in the spectral power of the bands (analysis within each band in the different conditions). The performance of a DT with C1 levels does not present great modifications when incorporating a second motor task independently of its workload.

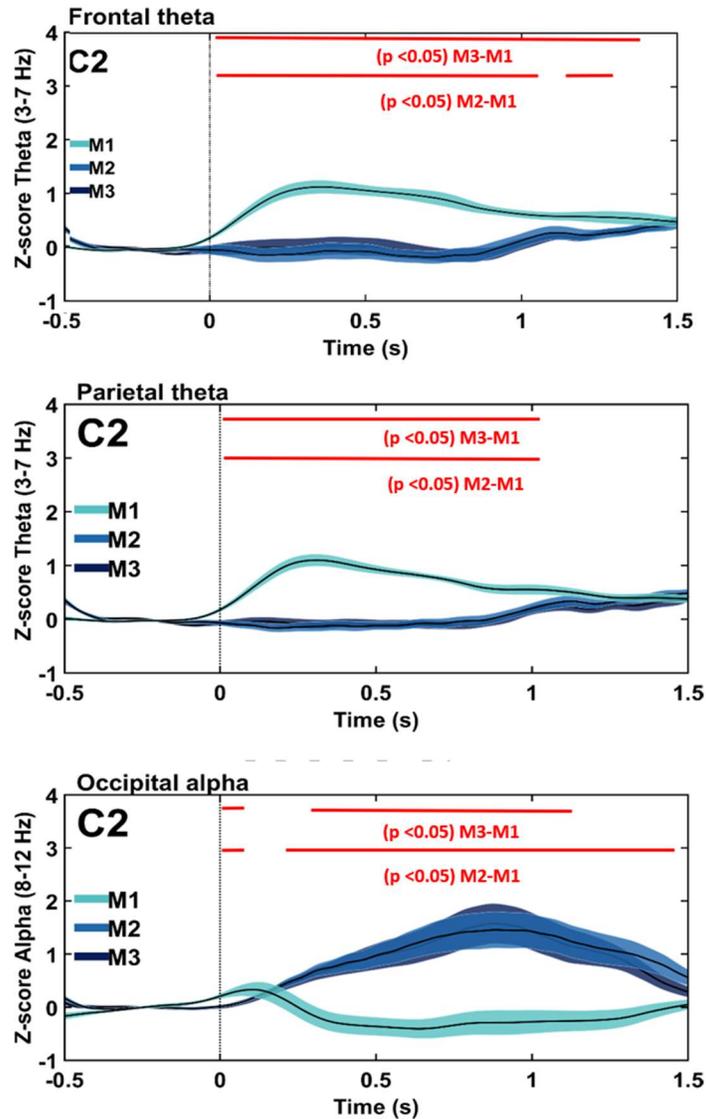


**Figure 4. Frontal theta (4 -7 Hz), Parietal theta (4 -7 Hz) and occipital alpha (8 – 12 Hz) for the cognitive task C1 in the dual tasks (DT).** The black line represents the mean of oscillatory power brain activity of all the subjects to frontal theta (top), parietal theta (center) and occipital alpha (bottom). The shaded area represents S.E.M. Motor workload (M1, M2 and M3) are shown in different colors. The dotted line indicates stimuli onset. The temporal profiles were compared between tasks using a Wilcoxon signed-rank test of non-overlapping 50 ms windows during the post-stimulus period (0 to 1500 ms). The p-values obtained were corrected for multiple comparisons using the false discovery rate procedure. No statistically significant differences are observed between the conditions of DT

### **8.2.2 Dual tasks: C2 vs. all level of motor workload**

At the C2 levels, no changes were observed when comparing ST versus DT with M1 (data presented in annex 8, Figure 8.2), however, when observing DT with M2 and M3 tasks, the increase of the occipital alpha band and a decrease of the theta band frontal-parietal can be observed (Figure 5). These changes in brain oscillation patterns are observed in the statistical comparisons test, which highlights the decrease of theta levels in the ROIs of the midline (frontal and parietal) and increasing alpha. The power of brain oscillations are presented in Figure 7 (at the middle), it is possible to observe that theta band (early and late) is increased, while the power of alpha (early and late) is diminished levels in all ROIs. In addition, it should be noted that the decrease of theta occurs with the presentation of the stimulus and continues throughout the test, while alpha begins to increase progressively after the execution time elapses. This increase in alpha occurs first in the occipital ROIs to progressively increase in the central area and then in the frontal zone. In this way, our results indicate that moving between a workload level of M1 and M2, while executing a C2, produces a decrease in performance and cognitive-motor interferential changes in alpha and theta activation patterns. The changes of power of brain oscillations are presented in detail in the Figure 7, where the effects are seen in the theta band (early and late) and late alpha. Demonstrating that theta decreases during the test and alpha increases in the final phase of this. The changes in brain oscillations are maintained by progressively increasing the difficulty of the MT. It might be for this reason that the comparison of the DT(M3) vs. DT(M2), no

significant differences are seen, maintaining the effect already reported (Figure 5). These results are also consistent with the behavioral results obtained, demonstrating that once the cognitive changes for the execution of a DT have been established, these are maintained if progression is made in the workload of the MT.



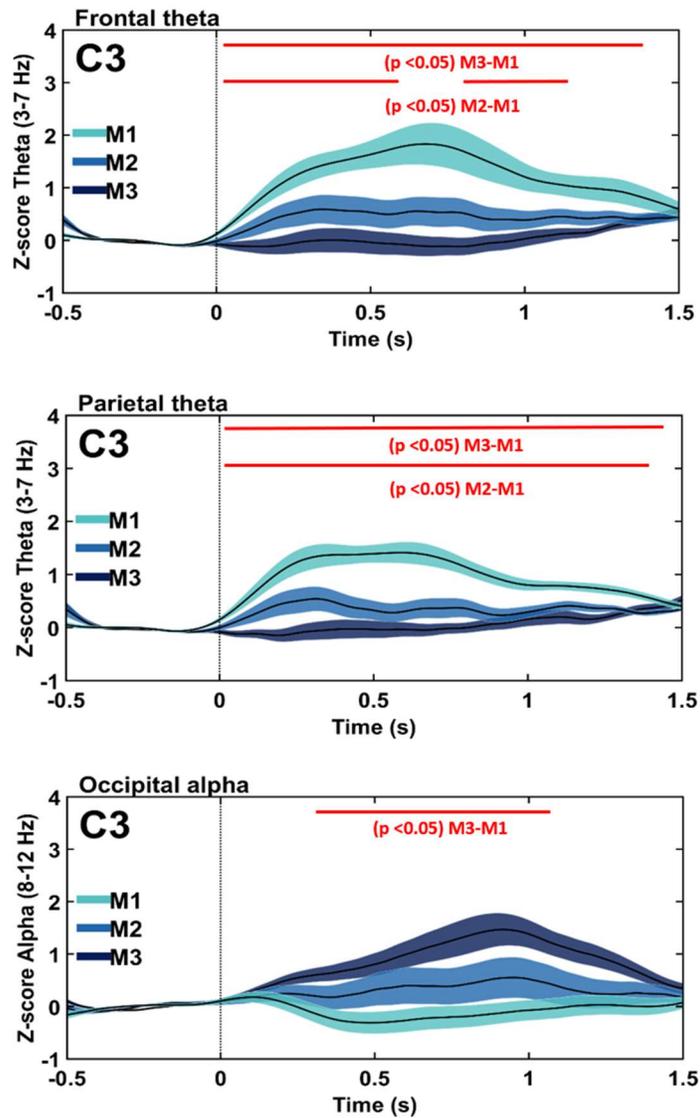
**Figure 5. Frontal theta (4 -7 Hz), Parietal theta (4 -7 Hz) and occipital alpha (8 – 12 Hz) for the cognitive task C2 in the dual tasks (DT).** The black line represents the mean of oscillatory power brain activity of all the subjects to frontal theta (top), parietal theta (center) and occipital alpha (bottom). The shaded area represents S.E.M. Motor workload (M1, M2 and M3) are shown in different colors. The dotted line indicates stimuli onset. The temporal profiles were compared between tasks using a Wilcoxon signed-rank test of non-overlapping 50 ms windows during the post-stimulus period (0 to 1500 ms). The p-values obtained were corrected for multiple comparisons using the false discovery rate procedure. The horizontal red lines represent the corrected significant differences. In the cognitive levels C2 and C3, the results show that theta decreases and alpha increases overtime as the motor workload is increased (M2 & M3).

### **8.2.3 Dual tasks: C3 vs. all level of motor workload**

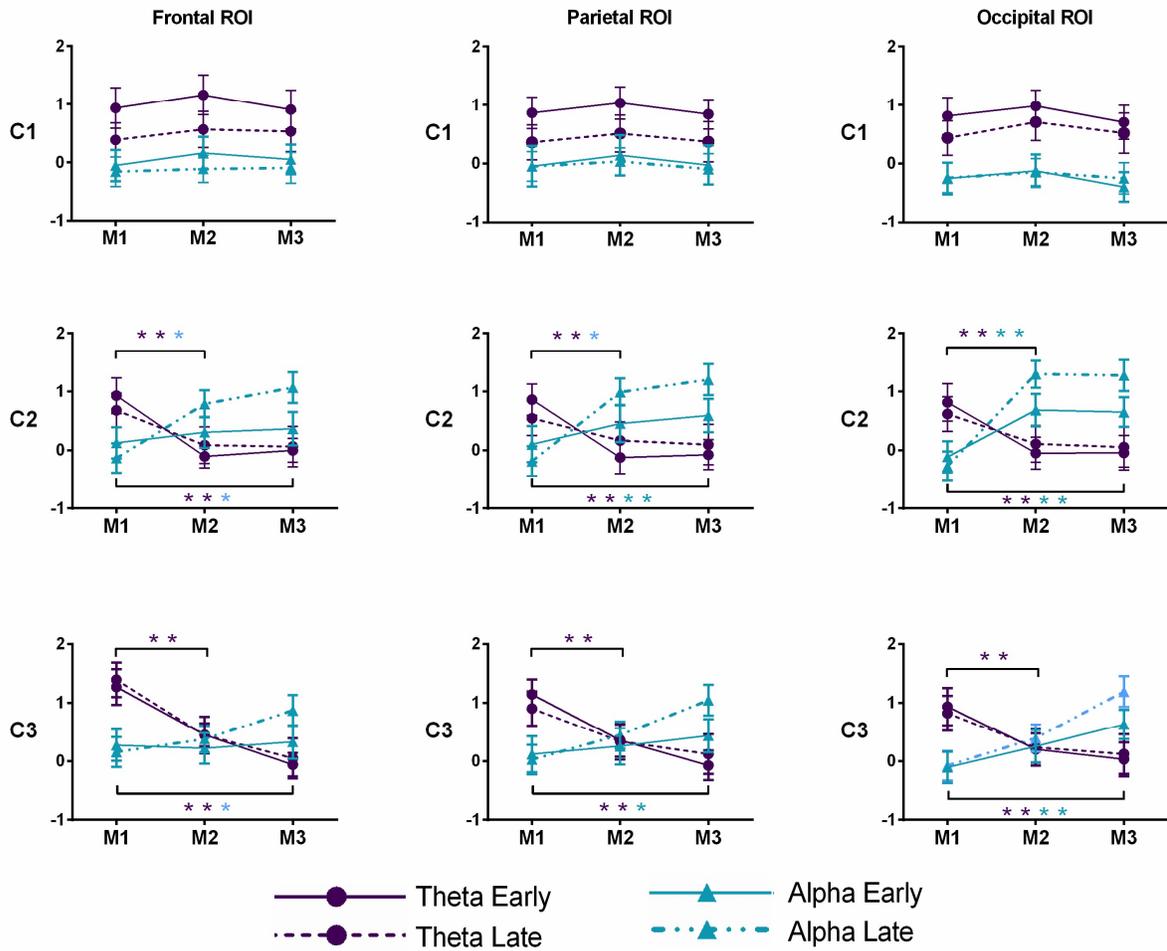
In relation to the hard CT, there are no changes when comparing ST versus DT with M1 (data reported in Annex 8, Figure 8.3). However, changes in brain oscillations are presented when comparing DT(M2) and DT(M3) vs DT(M1), showing a decrease in the Theta band in the all ROIs (Figure 6, frontal and parietal ROIs). on the other hand, Alpha did not show statistically significant changes when comparing DT (M2) vs DT(M1) but, when comparing the conditions DT(M3) vs DT(M1) It is possible to observe changes in the alpha band. These electrophysiological modifications are associated with the reported behavioral results, decreasing the performance in the task, and increasing the RT in both tasks (see figure 3).

When comparing DT with M3 vs. M2, the oscillatory pattern of theta and alpha is not modified, but performance continues decreasing and the RTs increasing. These results expose the existence of a second pattern of cognitive-motor interference that affects theta and alpha differently, decreasing the power of theta (early and late) without producing an increase in the power of alpha (early and late). See Figure 7 (at the bottom). All response patterns present in our experimental paradigm of DT cognitive-motor are represented in Figure 8.

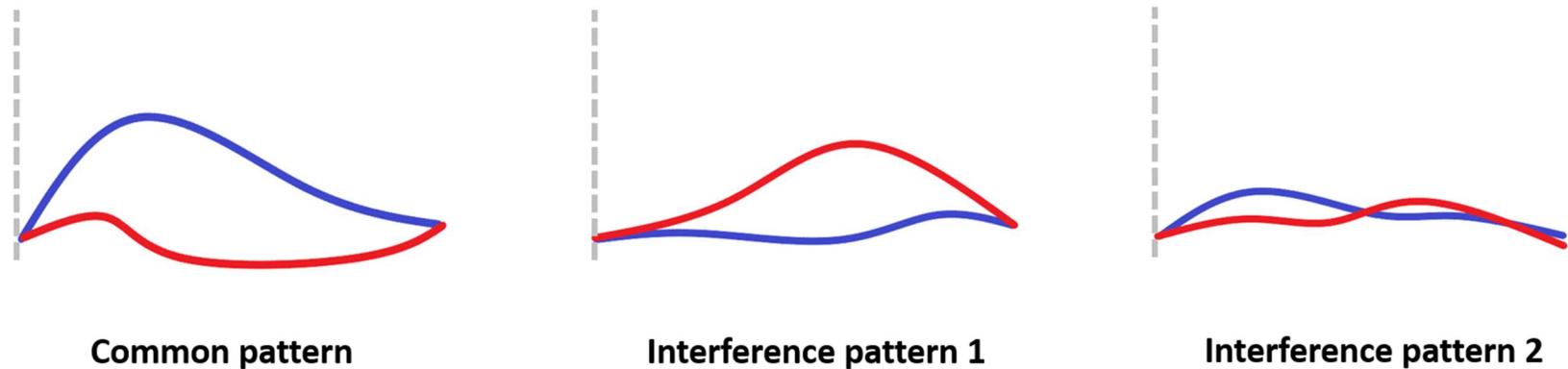
Figure 9 summarizes the results of nine combination of the DTs (figure 4,5 and 6). In the figure it is possible to observe the changes in the oscillatory pattern of the Alpha and Theta bands when the motor task increases in difficulty. In the figure it is easy to observe the 2 patterns of cognitive-motor interference described in the results.



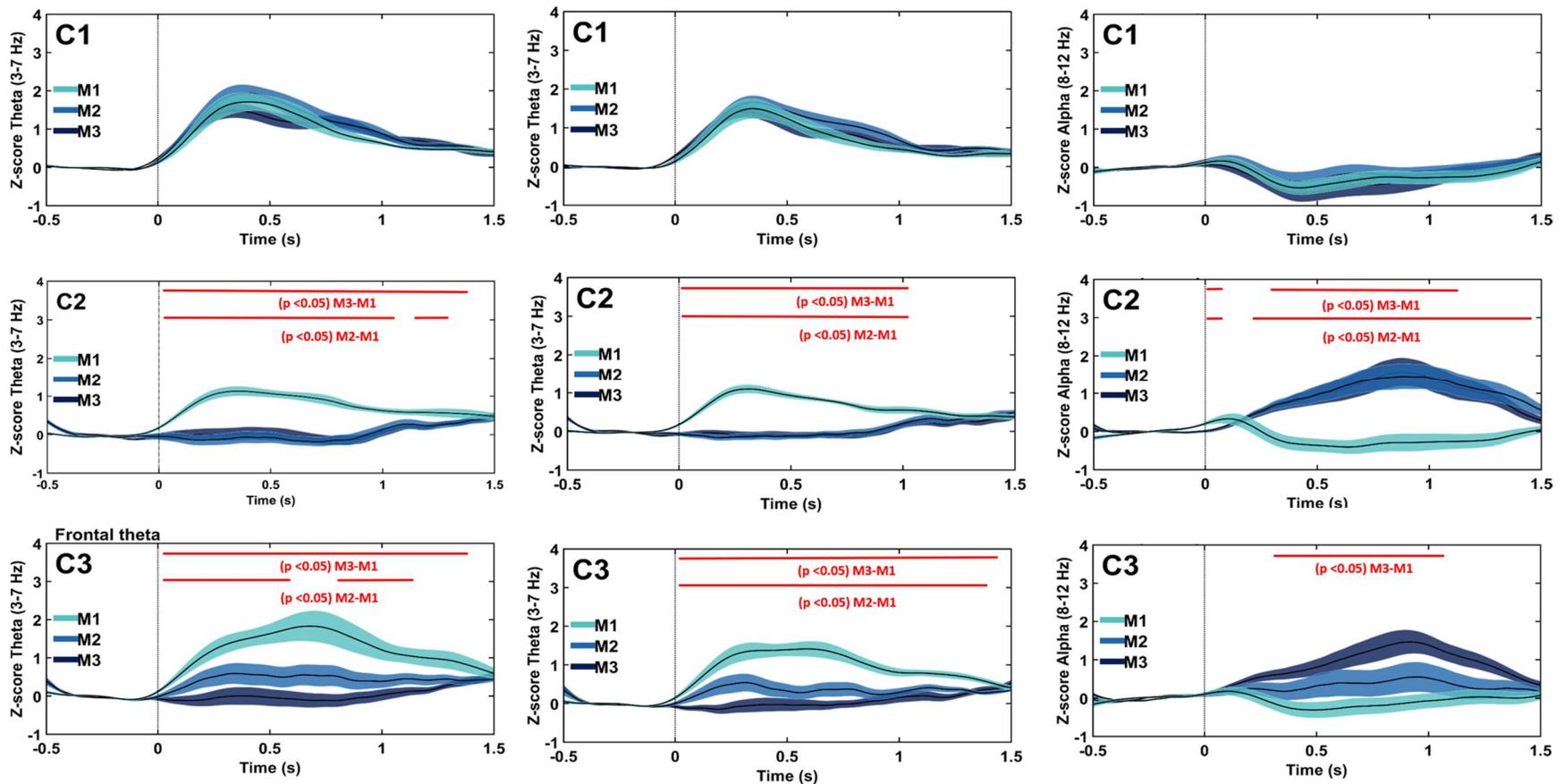
**Figure 6. Frontal theta (4 -7 Hz), Parietal theta (4 -7 Hz) and occipital alpha (8 – 12 Hz) for the cognitive task C3 in the dual tasks (DT).** The black line represents the mean of oscillatory power brain activity of all the subjects to frontal theta (top), parietal theta (center) and occipital alpha (bottom). The shaded area represents S.E.M. Motor workload (M1, M2 and M3) are shown in different colors. The dotted line indicates stimuli onset. The temporal profiles were compared between tasks using a Wilcoxon signed-rank test of non-overlapping 50 ms windows during the post-stimulus period (0 to 1500 ms). The p-values obtained were corrected for multiple comparisons using the false discovery rate procedure. The horizontal red lines represent the corrected significant differences. In the cognitive levels C2 and C3, the results show that theta decreases and alpha increases overtime as the motor workload is increased (M2 & M3).



**Figure 7. Theta (4 -7 Hz) and alpha (8 – 12 Hz) power time window average in the frontal, parietal and occipital ROIs in all cognitive workloads (C1, C2 and C3).** The early time window lasts from 0 to 650 ms and the late time window lasts from 650 to 1300 ms post-stimulus onset. The error bars represent the S.E.M.. The asterisk (\*) represents significant differences within each frequency band when comparing tasks (M2 - M1 upper; M3 - M1 down). The color of the asterisk represents the frequency band. In both C2 and C3 the increase in motor workload from M1 to M2 results in significant changes in power of the alpha and theta bands (early and late) at frontal, parietal and occipital ROIs. (see annexes 5,6 & 7: tables with the p values for each comparison).



**Figure 8. Representation of the changes in the oscillatory patterns of alpha and theta.** The image presents the representation of the different alpha (red) and theta (blue) patterns obtained during the experimental paradigm DT cognitive-motor. Common pattern (right) is found in the tests that the subject does not present cognitive-motor interference. In this pattern, both tasks compete for available attentional resources without affecting their performance when a motor task is incorporated. Interference pattern 1 (center) and interference pattern 2 (left) are the patterns that arise when incorporating a more complex motor task affecting performance during tests. In these 3 patterns is it arguably reflected the strategies of the WM in order to carry out the demands of the DT cognitive-motor on different workload levels.



**Figure 9. Overview of the Dual Tasks.** (combination of figures 3, 4 and 5). Frontal and Parietal theta (4 - 7 Hz) and occipital alpha (8 – 12 Hz) for the different cognitive tasks (C1, C2 and C3) in the dual tasks (DT). In the cognitive levels C2 and C3, the results show that theta decreases and alpha increases overtime as the motor workload is increased (M2 & M3). In addition, it is possible to observe the patterns represented in Figure 7.

## 9. DISCUSSION

The present study was designed to understand the mechanics of interferential cognitive-motor processes during a double task. The selected motor task does not need large body parts to be involved, minimizing possible movement artifacts that limit electrophysiological studies of this type. The results show how an increase in motor difficulty produces a change in the oscillatory patterns of theta and alpha during a demanding cognitive task. Specifically, when progressing in DT, there is a decrease in theta power (early and late) and an increase in alpha power (late) when a cognitive (C2) and motor (M2) tasks are performed simultaneously. This pattern was recorded in the cortical midline, involving the frontal, parietal and occipital cortex for alpha and for theta oscillations.

### **The role of theta in executive functions and interference processes.**

Power decrease in theta is contradictory with previous studies because its increase is a reliable marker of cognitive load (Jensen and Tesche 2002; Moran et al. 2010; Brouwer et al. 2012; Cavanagh and Frank 2014). The increase in frontal theta has been positively correlated with the increase in workload (Gevins et al. 1998; Jensen and Tesche 2002; Pesonen et al. 2007; Mitchell et al. 2008), as well as information coding and retrieval, decision-making, sustained attention, working memory processes (Klimesch 1999; Cavanagh and Frank 2014) and mental effort (Jensen and Tesche 2002; Jensen 2006; Nigbur et al. 2011; Cavanagh and Frank 2014).

The increase in the power of theta (early and late) was present only when there is low motor interference (C1 in all levels of motor workload, C2 in M1 level and C3 in M1 level), being concordant with the results of standard working memory tests. However, behavioral outcomes worsened when theta decreased (DT in C2 and C3 cognitive levels associated with M2 and M3). This result could indicate that the executive processes performed by the subjects were inefficient and insufficient to maintain the performance obtained at the previous level. Recently Reiser et al. presented evidence that supports our results, reporting the fall of frontal midline Theta power when the complexity of the motor task increases. In his experimental model, the lowest level of motor complexity was the standing position and the highest level walking in a natural environment. The event-related increase in Theta power was significantly decreased in the walking with obstacle course condition compared to standing, indicating a decline in focused attention for mental task execution while in motion. These results indicate that an increased movement complexity imposes a higher workload to the cognitive system, which, in turn, effectively reduces the availability of cognitive resources for the cognitive task. Therefore, the fall in the power of the theta band, and not its increase as proposed by Nigbur et al., could be one of the markers of the beginning of the interferential processes in the cortex (Nigbur et al. 2011).

## **Alpha and selective inhibition to keep the information in memory.**

Beyond the frontal middle theta increases in response to WM demands in a N-back task, there is a decrease in the alpha band (Pesonen et al. 2007; Popov et al. 2018). During the past decades, growing evidence indicates that brain oscillations in the alpha band not only reflect an “idle” state of cortical activity but also take a more active role in the generation of complex cognitive functions. Alpha activity has been associated with the fronto-parietal network, supporting the alpha oscillation relationship to top-down network interactions (Lenartowicz et al. 2016). Also, it has been related to thalamocortical interactions which are necessary for the process of selection and storage of information in working memory, including attentional processes (Klimesch 2012; Sadaghiani et al. 2012). The decrease of occipital alpha is associated to the increase of workload in tasks of mental effort, as well as the specific requirements of short-term memory (Schack et al. 2005; Klimesch et al. 2006). Our results, coherent with the literature, show a decrease in the power of alpha (early and late) when the power of theta increases. However, when cognitive load is increased (in C2), the power of alpha increases during the DT with medium and high motor workload. These results are clearly expressed in the time-frequency representations and spectral power analysis, specifically in late alpha. It has been shown that regions associated with task-irrelevant and potentially interfering processes exhibit an increase in alpha activation (Pfurtscheller and Lopes da Silva 1999).

The increase of alpha in the entire midline is a peculiar phenomenon because in general only the occipital electrodes present high alpha power occipital alpha is

recognized as an area in which it has the greatest power of this oscillation. Jensen et al. investigated the role of alpha using a modified Sternberg short-term memory task. They showed that the alpha band power increased when working memory load increased, specifically in the period of maintenance of the information. This alpha increase was detected in the occipital and temporal cortex (Jensen and Tesche 2002). The rise in the alpha band has also been proposed as a protector of working memory when affected by possible distractors that appear during the task, generating a process of active functional inhibition (Bonnefond and Jensen 2012). Our results also show alpha power increase, specifically in late alpha that could be used as a process of selective inhibition to keep the information in memory and avoid external distractors as proposed by different studies. However, we found alpha not only in occipital ROIs but also in frontal and parietal ROIs. Therefore, this alpha could be simultaneously additionally inhibiting the fronto-parietal network, a macro-scale brain network relevant for executive functions which is relevant for the fulfillment of the executive functions, affecting performance in the double task. We must bear in mind that the existence of "alphas" in midline ROIs could be associated with the nature of the source where it is being generated. Studies in animals and humans have shown varied alpha oscillators, which can be stimulated by different stimulus modalities (Başar 2012; Klimesch 2012). Alpha could be an example of how oscillatory patterns change when the task becomes highly complex, requiring a large amount of cognitive resources to avoid errors.

**Explanation of the cognitive-motor interference processes: Changes in the oscillatory patterns of theta and alpha could identify different strategies to maintain working memory during the test.**

We can observe that adding a movement of a second finger generates a decrease of theta and an increase in alpha. Possibly this phenomenon represents the existence of two types of storage strategies in working memory. First, to remember and maintain certain information over time, favoring its persistent storage and update (producing an increase in theta, modulated by attention). Second, to maintain information by inhibiting task irrelevant cortical regions, limiting the perception of the world, or by interference, task-relevant regions such as the frontoparietal network. This would give us the ability to change working memory strategies, depending on the performance, the difficulty of the task, and the available cognitive resources.

Unlike a modified Sternberg task which has longer information retention periods and has a very clear alpha occipital increase (Jensen et al. 2002; Jensen 2006; Bonnefond and Jensen 2012), the N-back is a fast-changing task and requires a constant update of information. That could be the reason for a prolonged inhibition as we observed. Subjects would block the continuous flow of external stimuli, resulting in a decrease in performance due to being unable to perceive the items that are being updated during the test. It may be that this change unconsciously occurs in this test, as the DT task progresses in difficulty. The double task used requires perception, storage, maintenance, comparison, remove stored items, inhibition, execution of cognitive responses, and multiple motor tasks (voice response and finger movement). This limitation in the updating process could be

given by the time it takes to perform the motor tasks, since the effect of moving a second finger contributes an average of 140 ms extra to the process, taking away time from the neural system to store the information correctly in the memory. However, in our data, no relationship was found when analyzing the motor RTs or the motor RTs plus the timing of the movement of the fingers, and hence, this idea is discarded. It is relevant to highlight that our results demonstrate a pattern of prioritization of the execution of the motor task before the cognitive task. This could be considered as a strategy to try to free the attention resources towards the cognitive task. This motor-cognitive sequencing arises spontaneously as the strategy developed at all levels of difficulty of the DT without exception.

We observe in our results that when DT is developed at a high cognitive workload level, a similar effect occurs, but this time only decreasing theta power in all evaluated ROIs. This effect is achieved with the incorporation of medium or high motor tasks in DT and, as we saw previously, associated with a drop-in performance and increased RTs. We hypothesize that this result is due to the fact that the imposed cognitive demand highly saturates the executive control system. This would constrain the system of moving towards the inhibitory pattern of working memory in which the alpha band power is increased, producing a greater variability of the responses of both tasks. This may even imply that the subject responds to the cognitive task using chance, limiting the possibility of observing an oscillatory pattern of interference as clear as presented in the DT with C2.

It should be noted that the M2 marks the transition between different oscillatory patterns, so the sequencing of two motor elements implies a heavy workload for the

executive systems, already loaded with information from the working memory, which, as shown by our ST results, already limits its functions. It is known that the complexity of the neural network of DT is more than just changes in the theta and alpha oscillations and involves other structures of the central nervous system, that still remain poorly understood.

Wu et al. used a paradigm of a cognitive-motor dual task to explore the integration of neural networks with fMRI while the subjects performed the fingers tapping and letter counting tasks simultaneously. They detected two cerebellar areas that were part of the neural network related to motor sequence performance in double tasks. The connectivity patterns were different when each of the ST was performed in isolation. They propose that when performing a DT, the neural network of each task is linked to integrate different areas of the brain (Wu et al. 2013). These cerebellar regions are parts of the executive networks (Buckner et al. 2011; Marvel et al. 2019), and their role in dual motor and cognitive task-processing is likely to integrate motor and cognitive networks and to perform the dual-task properly. In this line, a review of Marvel et al. demonstrated the convergence of neuroimaging data (fMRI) indicates that working memory is supported by the motor system, and in particular, by regions that are involved in motor planning and preparation, in the absence of overt movement. support the conclusion that motor networks are highly integrated into working memory processes and are critical for normal performance (Marvel et al. 2019).

The changes of control strategy of executive functions that imply modifications in the organization of the neural network, could be represented as cortical oscillatory

patterns specific for interferential processes in DT cognitive-motor. Our results are relevant because the start of the interference processes is clearly represented with progressive workloads.

### **Implications and projections**

Despite the great interest in the area of cognitive-motor interference in recent times, we must recognize that the motor component has always been considered a secondary element, because it produces "noise" in electrophysiological and imaging recordings. However, most neuroscience studies use it as a response system, without clearly considering its contribution in the different components of cortical activation. That is, the relevance of the coordination between sensorimotor and executive networks is often dismissed.

Moreover, the large number and variety of tests used to study cognitive-motor interference has been one of the sources of misunderstandings in the field. Moreover, the motor tasks previously reported (e.g. walking, moving arms, standing, sitting, staying on one foot, among others) have not modified progressively the motor workload. However, the movement of fingers allows the reduction in artifacts produced by movement, and it allows to gradually regulate the progression of motor workload. Thus, our task is a novel paradigm that enabled us to explore the effects of cognitive-motor interference progressively. To our knowledge, this is one of the first studies to show a change in the oscillating pattern of theta and alpha bands using the same task.

Finally, we propose that working memory can change dynamically depending on the difficulties and characteristics of the task. Besides, there are technical issues limiting our understanding of the involvement of neural networks of structures such as the cerebellum, in EEG records. This would explain a large number of reports that show diverse and occasionally conflicting data about working memory using EEG, MEG, fMRI, among others. The phenomenon of interference does not merely allow us to look analytically at each of the stages of these processes because, during the whole test, they are continually developing an overlap of functions. The tasks we used are very close to the reality experienced day by day, so despite being complex to interpret, they open the door to study the brain during multitasking. Given these results, it is essential to carry out studies of neural connectivity and to understand the differences existing on each test that we use to assess the interference of cognitive-motor functions.

## 10. CONCLUSION

The results of this research present clear evidence of how a simple (i.e., not involving large motor segments) motor task can affect the development of a cognitive task, decreasing performance of DT. The interference pattern arises when a DT is performed with a medium (C2) or hard (C3) cognitive workload and a medium (M2) or hard (M3) motor workload. Therefore, not all cognitive-motor DTs generated interference.

Cognitive-motor interference is mainly represented in the decrease of theta power in all the ROIs used. This effect is accompanied by a simultaneous increase of occipital alpha in the middle line of the scalp. The changes in behavior are associated with the change of the cortical oscillatory pattern, suggesting that the spectral power of EEG theta and alpha bands can serve as a neural marker of cognitive-motor interference.

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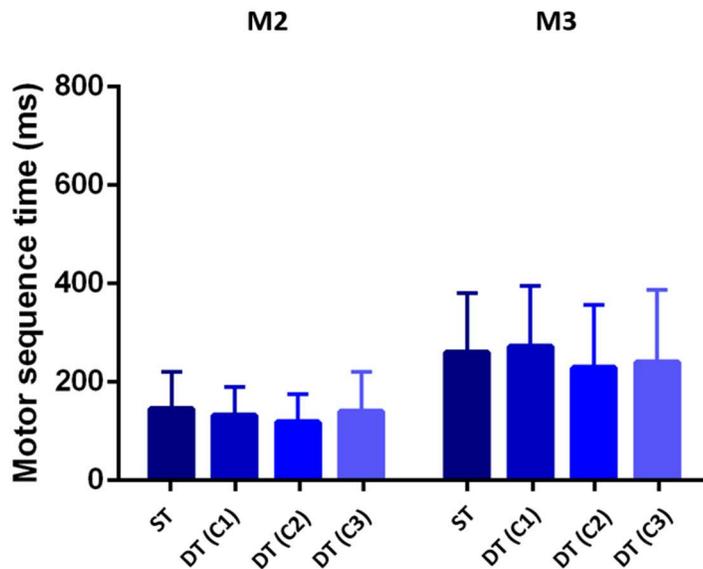
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## 12. ANNEXES

### Annex 1 - Motor sequence time (coordination between fingers).



Motor sequence time (coordination between fingers) that represents the time it took to perform the sequence of the fingers. It was only considered for motor workload M2 and M3. No changes were observed in motor sequence times when performed with different levels of cognitive workload in DT. The asterisk represents the significant differences (\*  $p < 0.05$ ) between the different levels of workload. **ST**: single task; **DT**: dual task; **C1**: cognitive task easy; **C2**: cognitive task medium; **C3**: cognitive task hard; **M2**: motor task medium; **M3**: motor task hard. Error bars = S.E.M.

**Table 1.1** Results of Friedman test and Dunn's multiple comparisons for Motor sequence time (M2).

**Motor sequence - M2**

Dunn's multiple comparisons test	Difference in rank sums	P	Adjusted P Value
ST vs DT(C1)	13	ns	0,3963
ST vs DT(C2)	15	ns	0,2037
ST vs DT(C3)	14	ns	0,2866
DT(C1) vs DT(C2)	2	ns	> 0,9999
DT(C1) vs DT(C3)	1	ns	> 0,9999
DT(C2) vs DT(C3)	-1	ns	> 0,9999

Friedman statistic = 5,960 , n= 14, p < 0,05

\*p < 0,05

**Table 1.2** Results of Friedman test and Dunn's multiple comparisons for Motor sequence time (M3).

**Motor sequence - M3**

Dunn's multiple comparisons test	Difference in rank sums	P	Adjusted P Value
ST vs DT(C1)	15	ns	0,2037
ST vs DT(C2)	16	ns	0,1422
ST vs DT(C3)	3	ns	> 0,9999
DT(C1) vs DT(C2)	1	ns	> 0,9999
DT(C1) vs DT(C3)	-12	ns	0,5385
DT(C2) vs DT(C3)	-13	ns	0,3963

Friedman statistic = 8,040 , n= 15, p < 0,05

\*p < 0,05

**Annex 2 - Results of Friedman test and Dunn's multiple comparisons to percentage correct answers (Figure 2 A).**

**Table 2.1** Results of Friedman test and Dunn's multiple comparisons for correct answers (C1).

**C1**

Dunn's multiple comparisons test	Difference in rank sums	P	Adjusted P Value
ST vs DT(M1)	-11,5	ns	0,6236
ST vs DT(M2)	-1,5	ns	> 0,9999
ST vs DT(M3)	5	ns	> 0,9999
DT(M1) vs DT(M2)	10	ns	0,9442
DT(M1) vs DT(M3)	16,5	ns	0,118
DT(M2) vs DT(M3)	6,5	ns	> 0,9999

Friedman statistic = 8,525 , n= 14, p < 0,05  
 \*p < 0,05

**Table 2.2** Results of Friedman test and Dunn's multiple comparisons for correct answers (C2).

**C2**

Dunn's multiple comparisons test	Difference in rank sums	P	Adjusted P Value
ST vs DT(M1)	9	ns	> 0,9999
ST vs DT(M2)	23,5	**	0,0054
ST vs DT(M3)	31,5	****	< 0,0001
DT(M1) vs DT(M2)	14,5	ns	0,2421
DT(M1) vs DT(M3)	22,5	**	0,0088
DT(M2) vs DT(M3)	8	ns	> 0,9999

Friedman statistic = 24,22 , n= 14, p < 0,05  
 \*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Table 2.3** Results of Friedman test and Dunn's multiple comparisons for correct answers (C3).

**C3**

Dunn's multiple comparisons test	Difference in rank sums	P	Adjusted P Value
ST vs DT(M1)	-2	ns	> 0,9999
ST vs DT(M2)	24	**	0,0042
ST vs DT(M3)	32	****	< 0,0001
DT(M1) vs DT(M2)	26	**	0,0014
DT(M1) vs DT(M3)	34	****	< 0,0001
DT(M2) vs DT(M3)	8	ns	> 0,9999

Friedman statistic = 34,96 , n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Annex 3 - Results of Friedman test and Dunn's multiple comparisons to cognitive reaction time (Figure 2 B).**

**Table 3.1** Results of Friedman test and Dunn's multiple comparisons for cognitive reaction time (C1).

**C1**

Dunn's multiple comparisons test	Difference in rank sums	P	Adjusted P Value
ST vs DT(M1)	-15	ns	0,2037
ST vs DT(M2)	-17	ns	0,0975
ST vs DT(M3)	-30	***	0,0001
DT(M1) vs DT(M2)	-2	ns	> 0,9999
DT(M1) vs DT(M3)	-15	ns	0,2037
DT(M2) vs DT(M3)	-13	ns	0,3963

Friedman statistic = 18,12 , n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Table 3.2** Results of Friedman test and Dunn's multiple comparisons for cognitive reaction time (C2).

**C2**

Dunn's multiple comparisons test	Difference in rank sums	P	Adjusted P Value
ST vs DT(M1)	-17	ns	0,0975
ST vs DT(M2)	-31	****	< 0,0001
ST vs DT(M3)	-30	***	0,0001
DT(M1) vs DT(M2)	-14	ns	0,2866
DT(M1) vs DT(M3)	-13	ns	0,3963
DT(M2) vs DT(M3)	1	ns	> 0,9999

Friedman statistic = 15,16 , n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Table 3.3** Results of Friedman test and Dunn's multiple comparisons for cognitive reaction time (C2).

**C3**

Dunn's multiple comparisons test	Difference in rank sums	P	Adjusted P Value
ST vs DT(M1)	-11,5	ns	0,6236
ST vs DT(M2)	-19	*	0,0434
ST vs DT(M3)	-19,5	*	0,0351
DT(M1) vs DT(M2)	-7,5	ns	> 0,9999
DT(M1) vs DT(M3)	-8	ns	> 0,9999
DT(M2) vs DT(M3)	-0,5	ns	> 0,9999

Friedman statistic = 10,01 , n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Annex 4 - Results of Friedman test and Dunn's multiple comparisons to motor reaction time (Figure 2 B).**

**Table 4.1** Results of Friedman test and Dunn's multiple comparisons for motor reaction time (C1).

**C1**

Dunn's multiple comparisons test	Difference in rank sums	P	Adjusted P Value
DT(M1) vs DT(M2)	3	ns	> 0,9999
DT(M1) vs DT(M3)	6	ns	0,8201
DT(M2) vs DT(M3)	3	ns	> 0,9999

Friedman statistic =1,20, n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Table 4.2** Results of Friedman test and Dunn's multiple comparisons for motor reaction time (C2).

**C2**

Dunn's multiple comparisons test	Difference in rank sums	P	Adjusted P Value
DT(M1) vs DT(M2)	9	ns	0,3012
DT(M1) vs DT(M3)	3	ns	> 0,9999
DT(M2) vs DT(M3)	-6	ns	0,8201

Friedman statistic =2,80 , n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Table 4.3** Results of Friedman test and Dunn's multiple comparisons for motor reaction time (C3).

**C3**

Dunn's multiple comparisons test	Difference in rank sums	P	Adjusted P Value
DT(M1) vs DT(M2)	3	ns	> 0,9999
DT(M1) vs DT(M3)	3	ns	> 0,9999
DT(M2) vs DT(M3)	0	ns	> 0,9999

Friedman statistic = 0,40 n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Annex 5 - Results of Friedman test and Dunn's multiple comparisons to power time window Frontal ROI (Figure 6).**

**Table 5.1** Results of Friedman test and Dunn's multiple comparisons to power time window Frontal ROI (C1).

**Frontal - Theta early**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	4,5	ns	> 0,9999
DT(M1) vs DT(M3)	-4,5	ns	> 0,9999
DT(M2) vs DT(M3)	-9	ns	0,3012

Friedman statistic = 2,746 n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Frontal - Theta late**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	-6	ns	0,8201
DT(M1) vs DT(M3)	-4,5	ns	0,8935
DT(M2) vs DT(M3)	1,5	ns	> 0,9999

Friedman statistic = 1,32 n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Frontal - Alpha early**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	-10	ns	0,2038
DT(M1) vs DT(M3)	-5	ns	> 0,9999
DT(M2) vs DT(M3)	5	ns	> 0,9999

Friedman statistic =3,333 n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Frontal - Alpha late**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	-1	ns	> 0,9999
DT(M1) vs DT(M3)	-5	ns	> 0,9999
DT(M2) vs DT(M3)	-4	ns	> 0,9999

Friedman statistic = 0,9333 n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Table 5.2** Results of Friedman test and Dunn's multiple comparisons to power time window Frontal ROI (C2).

**Frontal - Theta early**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	17	**	0,004
DT(M1) vs DT(M3)	19	***	0,001
DT(M2) vs DT(M3)	2	ns	> 0,9999

Friedman statistic =15,37 n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Frontal - Theta late**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	14	*	0,0245
DT(M1) vs DT(M3)	16	**	0,0075
DT(M2) vs DT(M3)	2	ns	> 0,9999

Friedman statistic =10,86 n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Frontal - Alpha early**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	-9	ns	0,2671
DT(M1) vs DT(M3)	-3	ns	> 0,9999
DT(M2) vs DT(M3)	6	ns	0,7707

Friedman statistic = 3,01 n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Frontal - Alpha late**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	-18	**	0,002
DT(M1) vs DT(M3)	-21	***	0,0002
DT(M2) vs DT(M3)	-3	ns	> 0,9999

Friedman statistic =18,43 n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Table 5.3** Results of Friedman test and Dunn's multiple comparisons to power time window Frontal ROI (C3).

**Frontal - Theta early**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	13,5	*	0,0323
DT(M1) vs DT(M3)	16,5	**	0,0025
DT(M2) vs DT(M3)	-3	ns	> 0,9999

Friedman statistic = 11,24 n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Frontal - Theta late**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	17,5	**	0,0028
DT(M1) vs DT(M3)	15,5	*	0,0102
DT(M2) vs DT(M3)	-2	ns	> 0,9999

Friedman statistic =13,35 n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Frontal - Alpha early**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	7	ns	0,5578
DT(M1) vs DT(M3)	5	ns	> 0,9999
DT(M2) vs DT(M3)	-2	ns	> 0,9999

Friedman statistic = 1,857, n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Frontal - Alpha late**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	-12	ns	0,0702
DT(M1) vs DT(M3)	-18	**	0,002
DT(M2) vs DT(M3)	-6	ns	0,7707

Friedman statistic = 12, n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Annex 6 - Results of Friedman test and Dunn's multiple comparisons to power time window Parietal ROI (Figure 6).**

**Table 6.1** Results of Friedman test and Dunn's multiple comparisons to power time window Parietal ROI (C1).

**Parietal - Theta early**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	5	ns	> 0,9999
DT(M1) vs DT(M3)	7	ns	0,6039
DT(M2) vs DT(M3)	2	ns	> 0,9999

Friedman statistic =1,733 n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Parietal - Theta late**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	8	ns	0,4326
DT(M1) vs DT(M3)	10	ns	0,2038
DT(M2) vs DT(M3)	2	ns	> 0,9999

Friedman statistic =3,73, n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Parietal - Alpha early**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	-11	ns	0,134
DT(M1) vs DT(M3)	-7	ns	0,6039
DT(M2) vs DT(M3)	4	ns	> 0,9999

Friedman statistic =4,1 n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Parietal - Alpha late**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	-10	ns	0,2038
DT(M1) vs DT(M3)	-5	ns	> 0,9999
DT(M2) vs DT(M3)	5	ns	> 0,9999

Friedman statistic =3,33 n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Table 6.2** Results of Friedman test and Dunn's multiple comparisons to power time window Parietal ROI (C2).

**Parietal - Theta early**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	13	*	0,0422
DT(M1) vs DT(M3)	17	**	0,004
DT(M2) vs DT(M3)	4	ns	> 0,9999

Friedman statistic = 11,29 n= 14, p < 0,05  
 \*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Parietal - Theta late**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	14,5	*	0,0185
DT(M1) vs DT(M3)	15,5	*	0,0102
DT(M2) vs DT(M3)	1	ns	> 0,9999

Friedman statistic = 10,95 n= 14, p < 0,05  
 \*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Parietal - Alpha early**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	-7	ns	0,5578
DT(M1) vs DT(M3)	1	ns	> 0,9999
DT(M2) vs DT(M3)	8	ns	0,3919

Friedman statistic = 2,714 n= 14, p < 0,05  
 \*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Parietal - Alpha late**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	-15,5	*	0,0102
DT(M1) vs DT(M3)	-19	***	0,001
DT(M2) vs DT(M3)	-3,5	ns	> 0,9999

Friedman statistic =14,87 n= 14, p < 0,05  
 \*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Table 6.3** Results of Friedman test and Dunn's multiple comparisons to power time window Parietal ROI (C3).

**Parietal - Theta early**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	20,5	**	0,003
DT(M1) vs DT(M3)	21,5	***	0,0001
DT(M2) vs DT(M3)	1	ns	> 0,9999

Friedman statistic = 21,45 n= 14, p < 0,05

\*p < 0,05, \*\*p < 0,01, \*\*\*p < 0,001

**Parietal - Theta late**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	20,5	***	0,0003
DT(M1) vs DT(M3)	18,5	**	0,0014
DT(M2) vs DT(M3)	-2	ns	> 0,9999

Friedman statistic =18,58 n= 14, p < 0,05

\*p < 0,05, \*\*p < 0,01, \*\*\*p < 0,001

**Parietal - Alpha early**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	-9	ns	0,3012
DT(M1) vs DT(M3)	-3	ns	> 0,9999
DT(M2) vs DT(M3)	6	ns	0,8201

Friedman statistic = 2,8 n= 14, p < 0,05

\*p < 0,05, \*\*p < 0,01, \*\*\*p < 0,001

**Parietal - Alpha late**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	-6	ns	0,8201
DT(M1) vs DT(M3)	-15	*	0,0186
DT(M2) vs DT(M3)	-9	ns	0,3012

Friedman statistic =7,6 n= 14, p < 0,05

\*p < 0,05, \*\*p < 0,01, \*\*\*p < 0,001

**Annex 7 - Results of Friedman test and Dunn's multiple comparisons to power time window Occipital ROI (Figure 6).**

**Table 7.1** Results of Friedman test and Dunn's multiple comparisons to power time window Occipital ROI (C1).

**Occipital - Theta early**

Dunn's multiple comparisons test	Difference in rank sums	P	Adjusted P Value
DT(M1) vs DT(M2)	2	ns	> 0,9999
DT(M1) vs DT(M3)	1	ns	> 0,9999
DT(M2) vs DT(M3)	-1	ns	> 0,9999

Friedman statistic = 0,13, n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Occipital - Theta late**

Dunn's multiple comparisons test	Difference in rank sums	P	Adjusted P Value
DT(M1) vs DT(M2)	5	ns	> 0,9999
DT(M1) vs DT(M3)	7	ns	0,6039
DT(M2) vs DT(M3)	2	ns	> 0,9999

Friedman statistic =, n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Occipital - Alpha early**

Dunn's multiple comparisons test	Difference in rank sums	P	Adjusted P Value
DT(M1) vs DT(M2)	-8,5	ns	0,3623
DT(M1) vs DT(M3)	-6,5	ns	0,7062
DT(M2) vs DT(M3)	2	ns	> 0,9999

Friedman statistic =2,67 n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Occipital - Alpha late**

Dunn's multiple comparisons test	Difference in rank sums	P	Adjusted P Value
DT(M1) vs DT(M2)	-8	ns	0,4326
DT(M1) vs DT(M3)	-4	ns	> 0,9999
DT(M2) vs DT(M3)	4	ns	> 0,9999

Friedman statistic = 2,13, n= 14, p < 0,05

\*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Table 7.2** Results of Friedman test and Dunn's multiple comparisons to power time window Occipital ROI (C2).

**Occipital - Theta early**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	15	*	0,0138
DT(M1) vs DT(M3)	15	*	0,0138
DT(M2) vs DT(M3)	0	ns	> 0,9999

Friedman statistic =10,71 , n= 14, p < 0,05  
 \*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Occipital - Theta late**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	17,5	**	0,0028
DT(M1) vs DT(M3)	15,5	*	0,0102
DT(M2) vs DT(M3)	-2	ns	> 0,9999

Friedman statistic = 13,35 n= 14, p < 0,05  
 \*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Occipital - Alpha early**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	-17	**	0,004
DT(M1) vs DT(M3)	-13	*	0,0422
DT(M2) vs DT(M3)	4	ns	> 0,9999

Friedman statistic =11,29 n= 14, p < 0,05  
 \*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Occipital - Alpha late**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	-18	**	0,002
DT(M1) vs DT(M3)	-18	**	0,002
DT(M2) vs DT(M3)	0	ns	> 0,9999

Friedman statistic = 15,43, n= 14, p < 0,05  
 \*p < 0,05 , \*\*p < 0,01 , \*\*\*p < 0,001

**Table 7.3** Results of Friedman test and Dunn's multiple comparisons to power time window Occipital ROI (C3).

**Occipital - Theta early**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	17	**	0,004
DT(M1) vs DT(M3)	19	***	0,001
DT(M2) vs DT(M3)	2	ns	> 0,9999

Friedman statistic = 15,57, n= 14, p < 0,05  
 \*p < 0,05, \*\*p < 0,01, \*\*\*p < 0,001

**Occipital - Theta late**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	14	*	0,0245
DT(M1) vs DT(M3)	22	***	0,001
DT(M2) vs DT(M3)	8	ns	0,3919

Friedman statistic = 17,71, n= 14, p < 0,05  
 \*p < 0,05, \*\*p < 0,01, \*\*\*p < 0,001

**Occipital - Alpha early**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	8	ns	0,3919
DT(M1) vs DT(M3)	10	ns	0,1765
DT(M2) vs DT(M3)	2	ns	> 0,9999

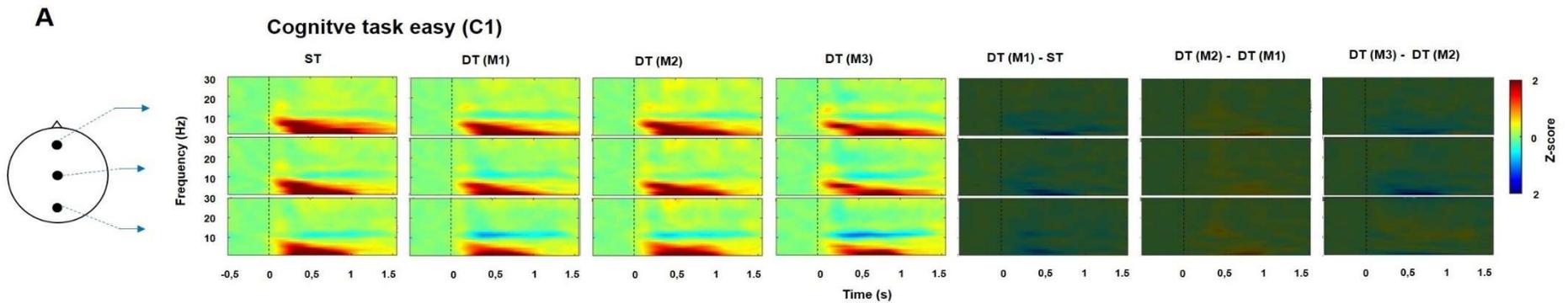
Friedman statistic =4, n= 14, p < 0,05  
 \*p < 0,05, \*\*p < 0,01, \*\*\*p < 0,001

**Occipital - Alpha late**

Dunn's multiple comparisons test	Difference in rank sums	p	Adjusted P Value
DT(M1) vs DT(M2)	-16	**	0,034
DT(M1) vs DT(M3)	-18	**	0,002
DT(M2) vs DT(M3)	0	ns	> 0,9999

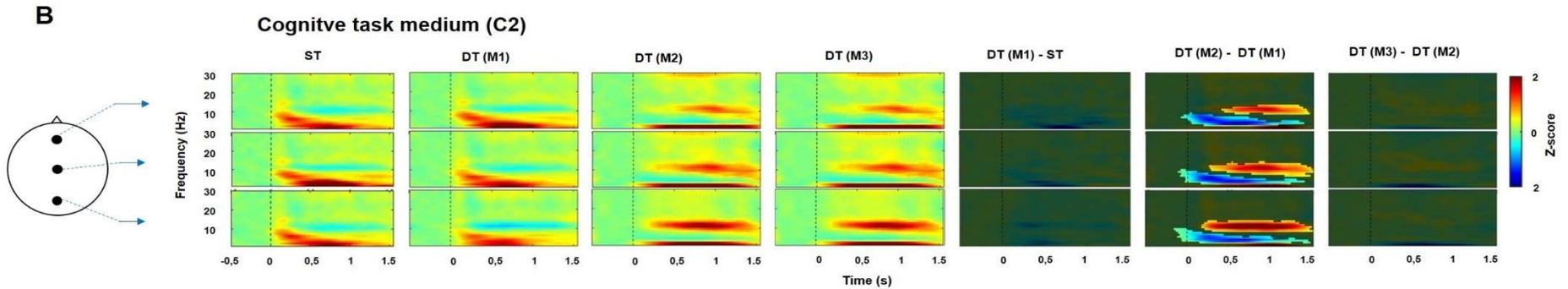
Friedman statistic = 15,43, n= 14, p < 0,05  
 \*p < 0,05, \*\*p < 0,01, \*\*\*p < 0,001

## Annex 8.1 - Time-frequency representation



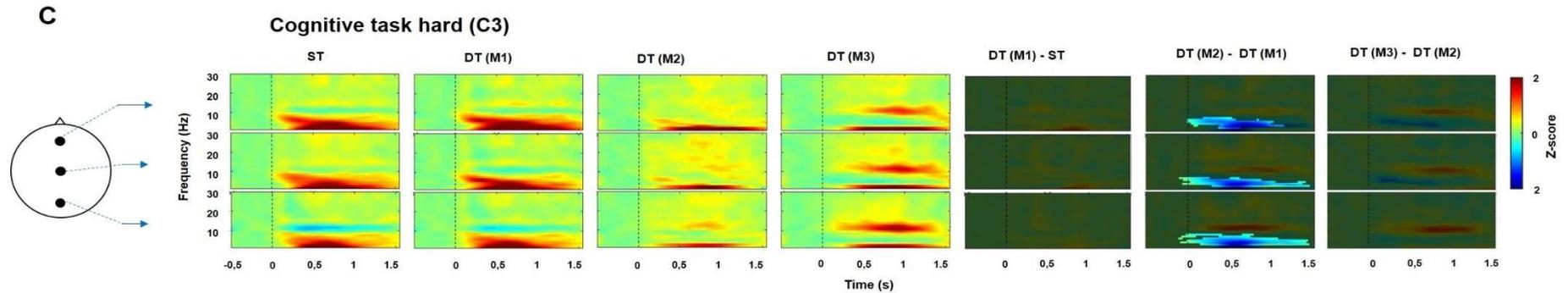
**A.- Time-frequency representation of the brain activation of all the subjects for the cognitive task easy (C1) in ST (single task) and DT (dual task) organized in relation to the workload of the MT (M1, M2 and M3).** The image of the head represents each of the 3 ROIs analyzed. In the graphs you can see how the brain oscillations vary each time the task increases the workload of the MT in a progressive way. Difference between two time-frequency graphs, the masking that is on the comparison allows highlighting the sites with significant differences between both conditions. The effects are represented as Red for positive changes and blue for negative changes. The time frequency charts show a range between 2 and 30 Hz, with a time interval of -0.5 to 1.5 s and a Z-score value of -2 to 2. The dotted line indicates time 0 where the stimuli occur.

## Annex 8.2 - Time-frequency representation C2



**B.- Time-frequency representation of the brain activation of all the subjects for the cognitive task easy (C2) in ST (single task) and DT (dual task) organized in relation to the workload of the MT (M1, M2 and M3).** The image of the head represents each of the 3 ROIs analyzed. In the graphs you can see how the brain oscillations vary each time the task increases the workload of the MT in a progressive way. Difference between two time-frequency graphs, the masking that is on the comparison allows highlighting the sites with significant differences between both conditions. The effects are represented as Red for positive changes and blue for negative changes. The time frequency charts show a range between 2 and 30 Hz, with a time interval of -0.5 to 1.5 s and a Z-score value of -2 to 2. The dotted line indicates time 0 where the stimuli occur. Positive cluster frontal ( $p=0,0339$ ), Positive cluster occipital ( $p=0,0219$ ). Positive cluster parietal ( $0,009$ ); Negative cluster frontal ( $p=0,0089$ ), Negative cluster occipital ( $p=0,009$ ). Negative cluster parietal ( $p=0,0061$ ), Negative cluster R temporal ( $p=0.0499$ ), Negative cluster L temporal ( $p=0,0091$ ).

## Annex 8.3 - Time-frequency representation C3



**C.- Time-frequency representation of the brain activation of all the subjects for the cognitive task easy (C3) in ST (single task) and DT (dual task) organized in relation to the workload of the MT (M1, M2 and M3).** The image of the head represents each of the 3 ROIs analyzed. In the graphs you can see how the brain oscillations vary each time the task increases the workload of the MT in a progressive way. Difference between two time-frequency graphs, the masking that is on the comparison allows highlighting the sites with significant differences between both conditions. The effects are represented as Red for positive changes and blue for negative changes. The time frequency charts show a range between 2 and 30 Hz, with a time interval of -0.5 to 1.5 s and a Z-score value of -2 to 2. The dotted line indicates time 0 where the stimuli occur. Negative cluster frontal ( $p=0,0059$ ), Negative cluster occipital ( $p=0,0178$ ). Negative cluster parietal ( $p=0,0049$ ), Negative cluster R temporal ( $p=0.0079$ ), Negative cluster L temporal ( $p=0,0136$ ).