Description of the "Spectro-temporal unfolding of temporal orienting of attention".

All behaviors unfold over time; therefore, our ability to perceive and adapt our behavior according to the temporal constraints of our environment is likely a fundamental requirement for successful behavior (Nobre et al., 2007).

Temporal preparation has been defined as our ability to anticipate and prepare an optimal response to forthcoming events in our environment (Nobre et al., 2007). Temporal preparation requires integration of different types of temporal information. On the one hand, information can be provided by temporal predictions, i.e. temporal orienting of attention. On the other hand, information can be afforded by the duration of the previous temporal events, namely the sequential effects (e.g., Capizzi et al., 2012).

The temporal orienting effect can be studied behaviorally by manipulating the foreperiod duration between a warning signal and a target stimulus. When the task requires participants to react as fast as they can to an impending target, a considerable reduction of reaction time (RT) is usually observed when the temporal uncertainty about its occurrence is minimized. That can be manipulated by the presentation of a temporal cue. If the duration of the interval is validly predicted by the cue, participants' RTs are shorter compared to when the duration of the interval cannot be predicted by the temporal cue.

Sequential effects are observed in a current short interval; the RT of the participants is faster when the previous interval was short as compared to when the previous interval was long. Sequential effects are not usually observed when the current interval is long; RTs of the participants in that case are faster independently of the duration length of the previous interval (Vallesi et al., 2007).

One main question is whether the two different effects of temporal preparation, temporal orienting and sequential effects, involve controlled or automatic processing. To address this question temporal orienting and sequential effects need to be measured under conditions of limited resources. One such exploration was offered in a study by Capizzi et al. (2012).

Capizzi et al. (2012) used a secondary demanding task and showed that temporal orienting effects, as indexed by the RT difference between valid and invalid trials at the short interval, were significantly reduced by performing a concurrent working memory task (see Figure 1A). In contrast, sequential effects, as indexed by the RT difference between a previous short and a previous long interval (at the current short trial) were preserved (see Figure 1B). Subsequently, they recorded event-related potentials (ERPs) under the same experimental conditions in order to investigate how the behavioral dissociation would be expressed in neural activity measures (Capizzi et al., 2013). As can be observed in Figure 1C, the EEG data showed that the dual-task condition impaired both temporal orienting (early vs. late cue conditions) and sequential effects.

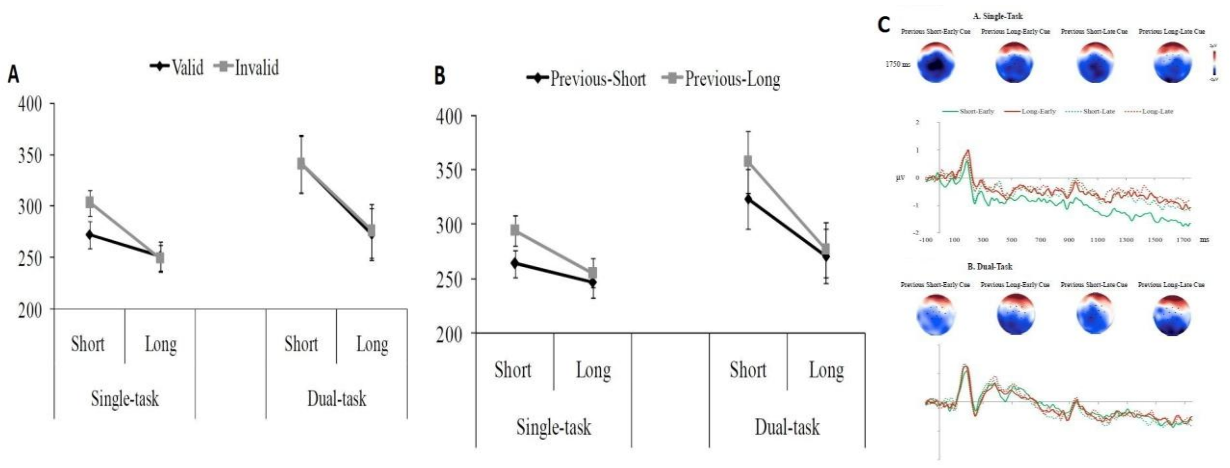

Figure 1 (**A**) Mean reaction times (RTs) as a function of Task (single-task, dual-task), Validity (valid, invalid) and Interval (short, long). Vertical bars represent the standard error of the mean. (**B**) Mean reaction times (RTs) as a function of Task (single-task, dual-task), Previous interval (short, long) and Interval (short, long). Vertical bars represent the standard error of the mean. (**C**) Grand average waveforms and topographies (with the corresponding electrodes used for the statistical analysis) of the CNV as a function of Cue (early, late) and Previous interval (short, long) for the single-task condition and the dual-task condition. Cued- locked CNV analysis revealed that effects of cueing and previous interval seemed to interact on the modulation of CNV amplitude under the single task condition, but both effects were eliminated under the dual task condition (Capizzi et al., 2013)

In this project we are focusing in the time- frequency analysis during the delay period (i.e., foreperiod) from the cue onset until the target onset at the short interval; we followed the results of Capizzi et al.'s (2013) study which showed that the CNV component was increased in the delay period when the previous foreperiod was short as compared to long.

Recent studies are concerned with the question of how oscillatory brain activity can provide a mechanism for regulating our temporal behavior (Cravo, 2011; Rohenkohl, 2001; Praamstra, 2007). Oscillatory brain activity may be one of the mechanisms underlying the operation of different brain areas during cognitive functions (Buzsaki, 2006).

When brain activity is recorded at the level of neural populations, the activity assumes a rhythmic temporal structure. Spectral analysis or Time-frequency analysis is the study of brain rhythms. Using Time-frequency analysis one can characterize the modulation of certain brain rhythms as those unfold in time.

Additionally, different brain regions can engage in synchronized brain activity in certain frequency bands. Such synchronization may support inter-areal communication which is likely fundamental to many of the cognitive functions producing behavior. Studying brain rhythms therefore has the potential of revealing mechanisms underlying cognitive function and behavior (Fries, 2009).

Oscillations at different frequencies are reflecting changes in the state of the brain. Oscillations have been categorized into five frequency bands; one ongoing question is which cognitive, perceptual or / and sensorimotor states are related to which frequency band. The delta band (0.5-3.5 Hz) is a frequency the activity of which has been correlated with working memory function, the brain reward system and learning. Theta band (4 – 7 Hz). Alpha band (8 -12 Hz) is one of the first frequencies that were described by Hans Berger, during the awake resting state. Activity in the alpha band has also been linked to working memory. More specifically, an alpha-band desynchronization is observed in the brain areas which are not related to the task performance.

Moreover the beta band (13-30 Hz) seems to reflect visual working memory (Engel & Fries, 2010). Finally, frequencies higher than 30 Hz, i.e. gamma -band (>30 Hz) are related to many functions including attention, motor preparatory activity and stimulus selection (Engel & Fries, 2010).

Previous studies in the field of temporal preparation (Rohenkohl et al., 2011; Cravo et al, 2011) have investigated oscillatory brain activity and how it is modulated over the time intervals in which target events are expected. Specifically, desynchronization of low frequency power (< 30 Hz) has been documented following the time course of predictable time intervals (figure 2).

In this project, we were interested in investigating the spectro-temporal profile of both temporal orienting and the sequential effects during the preparatory interval (foreperiod). Time/frequency analyses was focused on epochs locked to the cue onset and compared EEG activity related to early vs. late temporal expectations (temporal orienting) and EEG activity related to previous short vs. previous long foreperiods (sequential effects).

With the aforementioned approach we aim to clarify whether or not sequential effects and temporal orienting effects are mediated by the same brain activity.

The behavioral data from the previous study of Capizzi et al. (2012) indicated that temporal orienting and sequential effects are different aspects of temporal preparation and that sequential effects are related to automatic rather than to controlled processing unlike the temporal orienting effect. The EEG results were not totally consistent with the behavioral results concerning the sequential effects. Instead the ERPs point out that both effects can be modulated by the dual-task condition.

In order to better understand the phenomenon, we investigate the oscillatory activity and the potential differences between the two effects on the basis of the brain oscillations.

In our knowledge, there are not previous EEG studies investigating the oscillatory activity in temporal preparation induced by explicit symbolic cues (temporal orienting). In contrast, there are some studies that have focused on the oscillatory activity in temporal preparation driven by a regular rhythm (Rohenkohl et al., 2001). Our main question is whether oscillatory activity linked to temporal orienting based on symbolic cues will be analogous or different to temporal preparation driven by the presentation of regular rhythms (Rohenkohl et al., 2001).

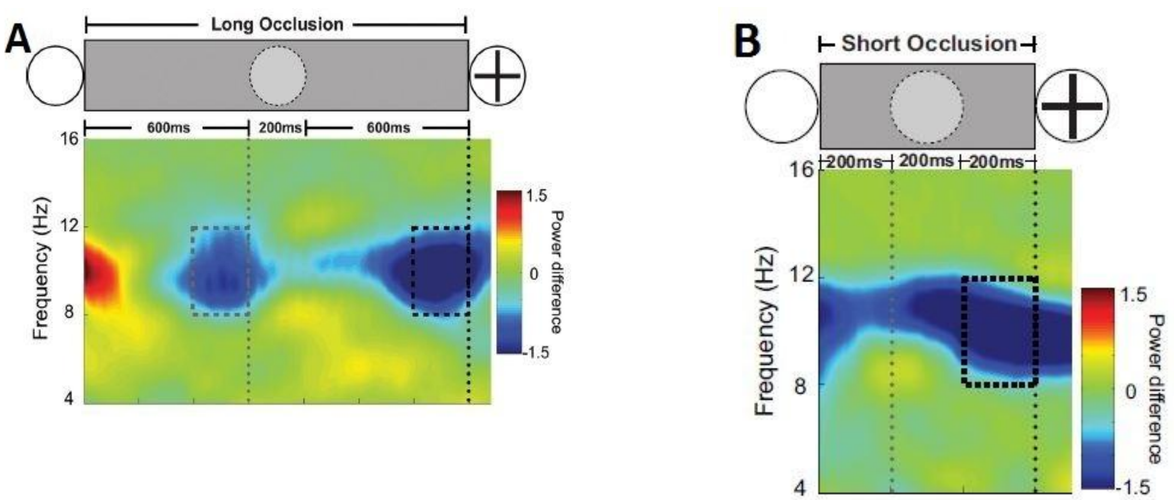

Figure2. Alpha activity during the **(A)** long and short **(B)** occlusion period. Time–frequency plots contrasting induced oscillatory activity in the rhythmic (valid) and arrhythmic (neutral) conditions in short- and long-occlusion trials. The figure shows the alpha-band desynchronization in the valid, rhythmic condition relative to the neutral, arrhythmic condition for short-occlusion trials [Valid Neutral]. The gray dotted line shows the time that the occluded stimulus would be presented. The black dotted line indicates the onset of the target. (Rohenkohl et al., 2011)

Hypothesis

When taking into account the dependent variables from the EEG, we first consider the different stages of processing invoked by the task: In a trial, participants will be required to encode perceptually the cue in order to generate task related information from it. During the delay period, participants are expected to maintain the information they gathered from the cue. This information is different for each task. Accordingly, EEG data will be evaluated for each of these stages:

EEG cue -response

- To investigate the representation of band-specific activity during the two tasks in temporal orienting effects and sequential effects.
- Unfolding of the power changes concerning the preparatory period.
- A detailed analysis of the time course of the changes in power across different frequencies and their relations to the task.

If temporal preparation mechanisms were similar for both rhythms and explicit cuing, then we would expect time-frequency analysis to reveal an effect in the low frequency bands as an index of temporal preparatory activity during the encoding of the temporal cue. More particular, we would expect to find a relative increased power in the alpha band in the delay period of the current trial when an early cue is preceded by a short interval as compared to the power in the delay period in the current trial when a late cue is preceded by a short interval, as an index of regulation of the temporal orienting effect.

Additionally we would expect time- frequency analysis to reveal an increase in power in the beta band during the single and dual task in the central and frontal brain areas as an index of the temporal orienting effects which will indicate that temporal orienting involves controlled processing. In contrast, we would not expect to find the same pattern as an index of the sequential effects. That would indicate that, as the behavioral data suggest, sequential effects involve automatic processing

Within this project we aim to shed more light on how the temporally orienting of attention (as indexed by the temporal orienting effects and sequential effects) can be revealed by oscillatory brain activity.

Materials and methods

Re- analysis of the dataset from behavioral and EEG data from the previous study Capizzi et al. (2012;2013).

Participants. Twenty-two participants (age range: 22-35 years, 2 men) gave informed concern to participate in the experiment. They were students from the University of Granada and they took part in the experiment in exchange for course credits or cash payment of 15 Euro. The study was approved by the local ethics committee and was conducted according to the guidelines of the Declaration of Helsinki. They had normal or corrected-to-normal visual acuity and reported having normal colour vision. Data from 8 participants were discarded because of excessive eye-movement or other artifacts. The remaining 14 participants were used for both spectral temporal analyses. All except of three participants were right-handed and they had visual acuity normal or corrected to normal, as well as normal colour vision.

Apparatus. The Stimulus was created and presented with Biological E-prime software (Schneider, Eschman, & Zuccolotto, 2002), responses were collected by an Intel Core 2 Duo personal computer connected to a 17" LCD monitor. The computer running software (Schneider, Eschman, & Zuccolotto, 2002), was connected to a Macintosh computer (Power PC G5) that recorded continuous EEG. The stimuli were projected centrally in a black background.

Stimuli and task. All participants were tested in a silent, dimly illuminated and electrical shield room. The temporal cue consisted of a short (3.4ºx 1.3º visual angle) or long (7.5º x 1.3º) line displayed in the following three colours; red, green or blue. The short line indicated that the target would probably appear early (after 1000 ms) and the long line indicated that the target would probably appear late (after 2000 ms). The target stimulus was a white dot (diameter: 1.5º).

The experiment was modeled after Posner's spatial orienting task (Posner, Snyder & Davidson, 1980), a symbolic cue predicts with high probability a specific time interval (i.e. early versus late) in which the target stimulus would occur.

A trial of the task block began with the presentation of a blank screen for a random duration between 500 and 1000ms. The temporal cue (either a short or a long line), filled with one of three colors -red, green, or blue- was then displayed for 750ms. Each color was randomly generated in the beginning of each trial with the same probability of appearance. Following the cue, the screen remained blank for a variable delay of either 1 or 2 seconds, depending on the

time interval for that trial. After the time interval elapsed, the target stimulus was presented for 100ms and then will disappear. Participants had to respond to the target onset as fast as possible by pressing the either the leftmost or rightmost key on a 4-key numeric keypad with the index finger of their preferred hand. They were explicitly informed that the temporal cue will help them to predict the occurrence of the target forthcoming stimulus. A visual feedback message will be displayed for 500ms either in case a premature response was given before the onset of the target ("wait for the target") or if no response was made more than 1100ms after the offset of the target ("respond faster"). Following the response to the target, or after 1100 ms in case of no response, the next trial will begin. For this condition the participants will be told that the color is irrelevant to the task and they have to ignore it (see Figure 3. Cappizi et al., 2013).
In this experiment the participants performed a temporal orienting task (Coull & Nobre, 2008; Nobre, 2001), in which temporal expectancy was modulated between trials.

EEG recording. Participants seated in front of the computer monitor and were instructed to avoid eye blinks and movements during stimulus presentation. The EEG recording was performed using a 128-channel Geodesic Sensor Net™ (Tucker, Liotti, Potts, Russell, & Posner, 1994; see Figure 1-B), connected to n AC-coupled high-input impedance amlifier (200 MΩ, Net Amps™, Electrical Geodesics, Eugene, Oregon). The head-coverage included sensors lateral to and below both eyes to monitor horizontal and vertical eye movements (electrooculogram, EOG electrodes). Impedances for each channel were measured and adjusted until they were kept below 50 kΩ before testing, as recommended for the Electricl Geodesis high-input impedance amplifiers. Gain and zero calibration were performed prior to start of every recording. All electrodes were referenced to the vertex (Cz) during the recording and were algebraically re-referenced off-line to calculate the average reference. The EEG was amplified with a band pass of 0.1-100 Hz (elliptic filter) and digitized at a sampling rate of 250 Hz.

Preprocessing of the data. EEG preprocessing was performed using the Net Station Waveform Tools. The unfiltered EEG recordings were segmented in1850ms epochs, 100ms before stimulus onset and spanning 1750ms. Epochs contained extreme noise or drift (80μV) in any channel or eye blinks and eye movements in the eye channel (50μV), were rejected. Individual bad channels were replaced on a trial –by- trial with a specific spine algorithm (Perrin, Pernier, Bertrand & Echallier, 1989), but trials were discarded if more than ten channels were bad. A minimum of 30 trials per condition was required to ensure a sufficient signal- to- noise ratio. Baseline correction was performed for the analysis, [-100, 0] ms. Artifacts- free epochs were then re –referenced off- online to the average in order to eliminate the effects of reference-site activity and to generate an accurate estimation of scalp topography of the recorded electrical fields (Tucker et al., 1994).

Time frequency analysis. Time frequency analysis was performed in a total of fourteen subjects; after preprocessing the raw data, the data of four participants were not included in the overall analysis because they had less than 30 segments after preprocessing the data.

Time frequency analysis was performed on the data using the Fieldtrip toolbox (Oostenveld et al., 2011) for MATLAB. A time–frequency analysis of data during delay period was performed to test oscillatory brain activity related to temporal expectations. No filtering was performed for the time–frequency analysis. Data were analyzed for Previous Short trial followed by an early cue, Previous Short trial followed by a late cue, Previous Long trial followed by early cue and Previous Long trial followed by late cue, conditions. Epochs started 100 ms before cue onset and lasted 1750ms after. The same epoch duration was used for late- and early-cue trials. To analyze modulations in power of oscillatory brain activity, a z-score normalization was performed to all channels and a time–frequency transformation (2 cycles per time window) was applied to all electrodes in each trial using a Hanning taper. This transformation produced an estimate of oscillatory raw power for each time sample (in 4ms steps) and each frequency between 2 and 30 Hz (in 1 Hz steps).

We compared low-band power in the delay period after cue onset, between the four different conditions over the following electrodes; [T5-P7 T6-P8; P3 P4; PO7 PO8; PO3 PO4; O1 O2; CP3 CP4; Tp7 Tp8; FP1 FP2; F7 F8; F3 F4; FT7 FT8; FC2 FC3;T11 T12; C3 C4). We calculated the power changes in each channel concerning the different task conditions for each frequency band of interest (in 1 Hz steps) over each time point during the the preparatory period (in 4ms steps) for each subject.

Preliminary Results

Preliminary cue locked analysis showed that when an early cue is followed by a short interval there is higher power in lower frequencies as compared to the power when a late cue is followed by a short interval.

These results signify a difference in the power representation of the temporal preparation for explicit cuing compared when temporal preparation is guided by the presentation of a regular rhythm suggesting the involvement of dissociable mechanisms (Figure 4).

Statistical analysis will be performed to investigate the significance in the increase of the power in the low frequency bands of interest.

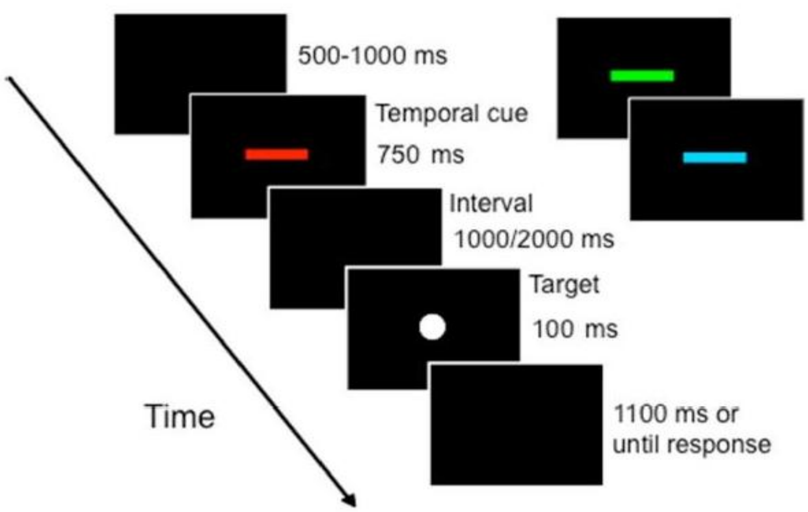

Figure 3. Schematic representation of trial structure. (Cappizi et al., 2013)

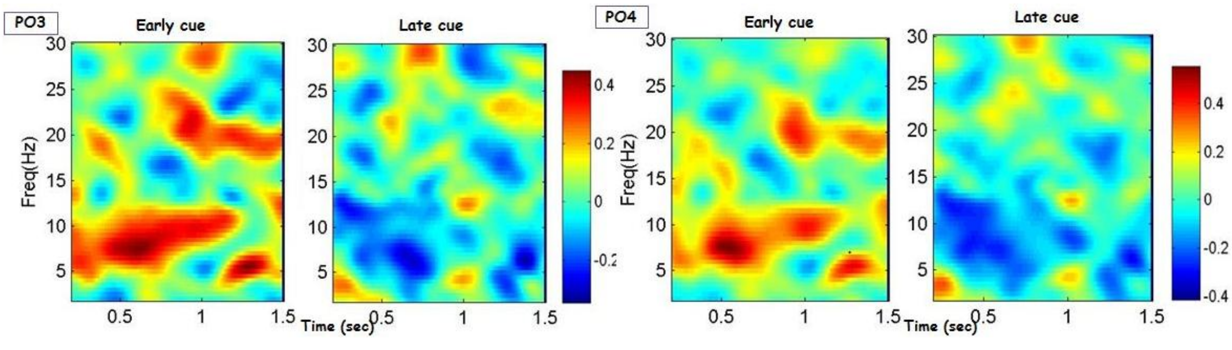

Figure 4. Time analysis of alpha and beta bands temporal spectral changes. Time frequency representation of activity measured at two electrode over the occipital cortex in the two conditions.

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