Implicit Orienting Of Attention In Time

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Abstract

Temporal attention has been studied in an analogous fashion to Posner's paradigm with mostly visual tasks and one modality at a time, inducing expectancies about the “when” certain targets will appear, which in turn facilitated performance and produced even early perceptual ERPs. On the other hand, based on the Dynamic Attending theory, attention fluctuates in time and is capable to entraining to external rhythms like auditory sequences. In this study, attention was implicitly modulated by using a metronome and the scope of the experiment was to investigate the effects on perception and motor preparation during the execution of a detection task. Subjects while listening to a metronome were asked to detect a cross (for the visual part) or an audio cue (for the auditory). Based on Jone's model for meter perception, founded on the Dynamic Attending theory, we hypothesised that targets coinciding with instances in time of different attentional level would produce different response times and ERPs. The results validated the model by showing that targets appearing on instances of higher attentional level produced a faster response and elicited modulated early and late components P1, N1 (amplitude) and N2 (latency) for both modalities. This implies that metronome implicitly influences attentional level producing crossmodal effects that are manifested with optimized perceptual and motor performance.

Introduction

Time is a fundamental property of our dynamic environment. Multiple phenomena of everyday life extend in time, such as music that entrains us to foot taping in synchrony, or speeding up to cross the street before the green light turns to red. Temporal information in different forms is all around us to facilitate our everyday interaction in the dynamic world. Increasing evidence cast the brain as a predictor (Nobre, Correa & Coull 2007) that uses temporal information to form expectations, orient attention in time and finally optimize behavior.

Selective spatial attention has been studied in Posner paradigm (1980) where spatial cues informed the subject about the side of the forthcoming target and stimulus processing was optimized yielding shorter RTs for valid cues comparing to invalid ones. Selective temporal attention has been studied in a similar way to Posner paradigm. Warning signals about the "when" of a target, are used to form temporal expectations which in turn produce faster RT in simple-RT and discrimination tasks (Miniussi 1999, Griffin 2001, Correa 2004, Correa 2006). Electrophysiological measurements show that temporal-orienting effect goes beyond motor preparation that produces speeded RT. It affects not just late motor processing as was initially thought (Miniussi 1999, Griffin 2001) but also early perceptual processing (Correa 2005). Late components such as N200 and P300 which are related to motor preparation are modulated along with early component N100 when a perceptually demanding task is required (Correa 2006). In a more ecological study (Doherty 2005) combined warning signals about the "where" and the "when" of the target were presented. The results produced an enhanced P100 comparing to when solely target location or time was presented revealing a synergistic effect of temporal and spatial orienting.

For a long time selective temporal attention has been studied for each modality separately, however and increasing number of studies have shown that there are many inter-modal links of attention in audition, vision and touch. ERP experiments studying the intermodal effects of attention (Talsma 2008) using audiovisual stimuli found that when auditory and visual stimuli were temporally aligned an enhancement of visual P100 was observed. In another study by Lange (2006) crossmodal effects of temporal attention were observed during an audio-tactile discrimination task. When subjects had to respond to tactile stimuli, processing of task-irrelevant audio stimuli was improved even at an early stage of 100ms (Lange 2006).

Attentional orienting in time is not obtained only in an explicit manner but also implicitly which is of great interest for two reasons. First it prevents subjects from developing strategies during task execution and second it may reveal a general mechanism which can be of potential use in medical cases like Parkinson's disease studies. For example recently the CNV, characteristic of explicit tasks that reflects stimuli anticipation was also obtained during implicit timing task (Praamstra 2006). In the latter ERP experiment, subjects confirmed that remained unaware of the slight deviances of the interstimulus interval in the range of 0.5s enabling a passive entrainment with SOAs of 1.5s and 2.0s while the corresponding CNV's time course was following the SOA duration. The neurophysiological evidence demonstrate that temporal expectation like interval's duration can be conditioned implicitly by regular sequences of stimuli. Another behavioral study (Olson 2001) used sequences of visual events to create a temporal context within which subjects had to search for a target. The results showed that implicitly learned sequences of visual events with variant duration, identity or spacio/temporal location, guide attention at specific points in time and facilitate task execution.

Although vision is the predominant modality where attention is manipulated, auditory sequences have also been used in a few studies as a mean to induce temporal orienting of attention (Large 1999, Jones 2002, Brochard 2003). The theoretical framework behind these studies is the dynamic attending theory (Jones 1976, Large and Jones 1999) which posits that attention occurs in the form of internal oscillations that can be entrained or driven by external rhythms. Internal attending rhythms generate expectations and anticipate future events. This is confirmed by auditory perception experiments (Large & Jones 1999) where listeners find it easier to detect a time change in isochronous than in non-isochronous auditory patterns since the isochronous pattern allows better attentional coordination. In the same study listeners were more accurate at judging time when the standard interval was anticipated based on a preceding sequence of isochronous IOIs and least accurate when this interval was unexpected. Similar expectancies are generated when subjects influenced by auditory sequences judge more accurately the pitch of rhythmically expected tones rather than unexpected (Jones 2002). The entrainment hypothesis is supported also by physiological evidence (Brochard 2003) where disruption of listener's expectancies produced larger amplitudes on the more accented beats.

In sum, the phenomenon of selective temporal attention has been mostly studied using explicit cues, one modality at a time and mostly with visual stimuli. In our experiment our intention was to go beyond these restrictions by using music as a mean to induce orienting attention in time. Music differs from simple auditory sequences, among others meter. Meter emerges while we listen to music and basically organises notes in time and allows us to perceive the beats. The phenomenal salience of certain notes as stronger comparing to others, like the first note on a ¾ waltz, doesn't happen because it is played louder or because the performer accentuated at this instant. Once this sense of beat is established it stays in the mind even when the music has stopped. Lerdahl & Jackendoff (1983) represented the metrical structure, or the alternation of strong and weak beats over time as a grid of beats at various time scales, as shown in Figure 1. Notes of greater metrical level or in other words the "strong beats" have many coinciding dots while the "weak beats" have less.

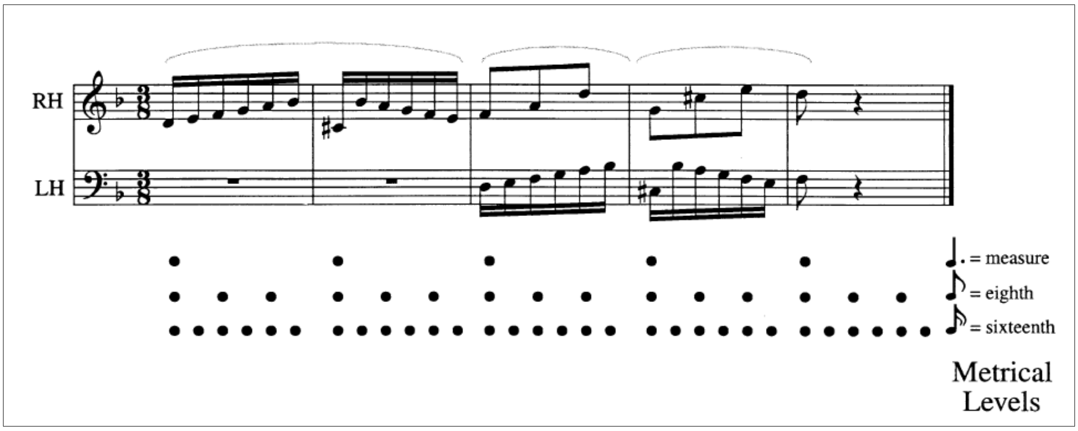

Figure 1. Opening section from 2-part invention in D-minor, by J.S. Bach. Metrical grid notation indicates metrical accent levels (bottom) with three levels.

The question is why and how we perceive this temporal regularity in music. Large & Palmer's approach (2002) is based on the Dynamic Attending theory and suggest that external rhythms are perceived as multiple internal oscillation of different periodicities. Precisely for each hierarchical metrical level there is an internal oscillation of specific period and phase. So whenever driven by musical rhythms this is due to internal oscillations phase-locked to the external musical events (Large &

Palmer 2002). Mathematically the internal oscillation is described by the expectancy function or a pulse of attentional energy modeled as a periodic probability density function, the von Mises distribution, which is shaped similarly to a Gaussian distribution. Figure 2 shows the modeled attentional level in form of the expectancy function for one cycle of a triple meter. Here a network of two coupled oscillators is used, which demonstrates in one measure the hierarchical property of the emphasised first beat and the weaker following beats.

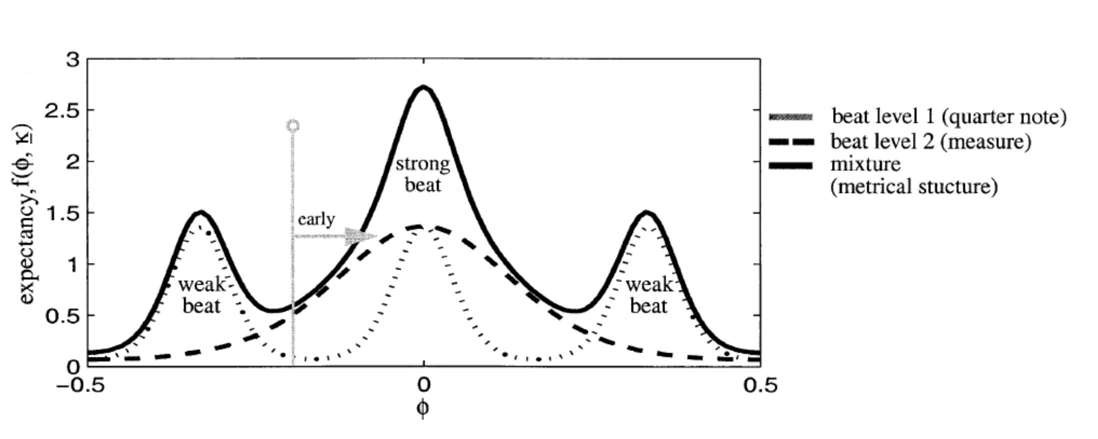

Figure 2. Model expectancies for a triple meter based on a mixture of two oscillations

However, the model of Jones has mainly be tested behaviorally and is not clear with respect to which kind of attention is involved in meter perception. Indeed, the model has been tested only for auditory attention, but it has not been investigated whether the theory of dynamic attending is also applicable on other modalities and whether this theory might even represent a model to explain cross-modal effects.

These exposed fields of research form the theoretical background which led us to integrate these approaches and to develop a new paradigm to investigate whether an implicitly induced synchronisation of attention in time via a metronome influences the processing of sensory input and motor preparation in a detection task.

Aim and Hypotheses

The present study investigated whether a periodic auditory sequence or metronome affects attentional processes. If level of attention fluctuates in time and we present targets at different moments in time then we should expect differences in RTs and ERPs for both modalities. More precisely, visual and audio stimuli presented on strong metrical points should yield shorter RTs and larger ERPs. This is like when temporal attention is manipulated explicitly we expect larger ERPs at the attended point in time than ERPs at the unattended point in time. The multimodal nature of the experiment permits also the study of any intermodal or cross-modal effects. Any differences found to ERPs during the execution of the vision task, these will be due to the influence of the metronome.

Method

Subjects

Twenty two subjects were tested in the experiment. All subjects reported normal hearing except one that was deaf in the left ear. Subject's age ranged between 21 and 37 years old with mean age 27. Nine participants have had musical education of five years or more. Three participants were left-handed. Subjects were paid for their participation and gave their consent to use the acquired data for further analysis

Experimental Design

Procedure. Subjects were sitting in a Faraday shielded room and had to perform a speeded response detection task either visual or audio. Specifically, subjects while listening to the metronome were asked to press a button straight after the presentation of the visual cue on the screen or the audio cue from the headphones. The visual cue was a cross that appeared on the center of the screen and the audio cue was a sound of different timbre to the metronome.

The experiment consisted of 2 blocks, one for audio targets and another for visual ones. Each block had 3 sessions each of 5 minutes. So in total the experiment lasted for 40 minutes including the pauses between sessions.

Experimental and Control Conditions. We chose four different experimental conditions in order to test the level of attention in different instances of the hierarchical structure of meter of the music. The independent variable manipulated in this experiment, is the moment in time, with respect to the metrical structure of music, chosen to present the cue, namely (see Fig):

1. on the strongest beat (the first beat in the bar)
2. just before the weakest beat (before the third beat in the bar)
3. on the weakest beat (the third beat in the bar)
4. just before the strongest beat (before the first beat in the bar)

These conditions were chosen as they correspond to distant values in the model regarding the predicted attentional level, and thus allow to test the model with a parametric approach. Furthermore, as can be seen in Figure 3 these positions are quite evenly distributed in the measure, which is important insofar as it reduces stimuli presentation predictability.

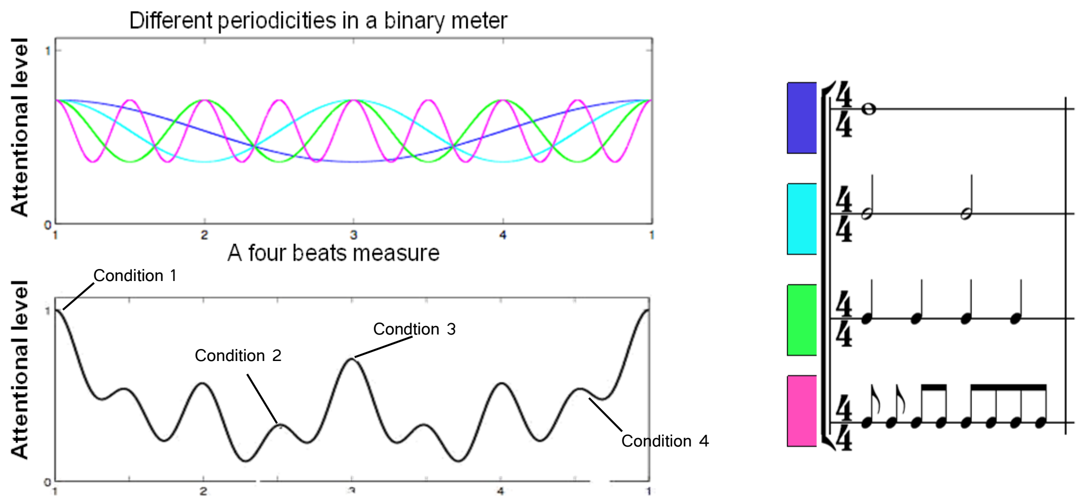

Figure 3. Large's model adapted for a binary meter of 4 beats, illustrated with 4 coupled oscillators tracking four periodicities (top). The arrows indicate the attentional levels which are predicted by the model at the instances of the visual stimulus onset in the four experimental conditions (bottom)

Stimuli and Material

Audio and visual stimuli. The musical stimuli consisted of a metronome which although lucks of musicality it has the required metrical structure hierarchy which is essential to focus and reveal just the entrainment effectuated by the temporal structure of music.

Auditory and Visual Task

The auditory task consisted of a speeded response task. While the subject was listening to the metronome a sound of different pitch was played in a certain order. Subjects had a response button in the right hand and were instructed to react as fast as possible to the sound of different pitch by pressing the button.

In a similar way during the visual task the subject had to perform a speeded response task. In a centered position on a black screen, placed at a distance of 80cm from the subject, a plus sign ("+") was presented in certain order. Subjects had a response button in the right hand and were instructed to react as fast as possible to the visual stimuli by pressing the button.

This task, although it does not present any difficulty cannot be done automatically. It demands a certain amount of attentional resources which we shall examine if they are affected by metronome or not. Additionally the task is not perceptually demanding, so if any effects are found at this level of activity then these should be most probably present also in more perceptually demanding tasks, like discrimination.

Data Acquisition and Processing

Data acquisition. We used an EEG configuration of 32channels (BioSemi ActiveView or Active 2) placed on a head cap, in the standard position over the right and left hemispheres (International 10/20 system (Jasper, 1958): Fz, Cz, Pz, Oz, Fp1, Fp2, AF3, AF4, F7, F8, F3, F4, Fc5, Fc6, Fc1, Fc2, T7, T8, C3, C4, Cp1, Cp2, Cp5, Cp6, P3, P4, PO3, PO4, P7, P8, O1, O2). These recordings sites plus two others over the mastoids were referenced to two central electrodes CRL. The data were then re-referenced offline to the algebraic average of the left and right mastoids. Before the recording of the EEG data it was checked that the impedance of all electrodes was below 20*K*Ω. The data were recorded at a sampling rate of 512 *Hz.*

EEG processing. For EEG data processing the EEGLAB interactive Matlab toolbox was used. Initially the data were re-referenced to the weighted sum of the two mastoids and filtered at a low cut-off frequency of 1*Hz*. After visual rejection of unsuitable (paroxysmal) portions of data, ICA was run in order to separate neural activity from muscle and blink artifacts. Components representing temporal or frontal muscular noise and eye blinks were removed from the set. On several sets a BSS (blind source separation) filter was applied as well so as to remove muscular noise. ERP data epoching was done 1s before and after stimulus presentation, giving a period of 2 sec which is also sufficient for running frequency analysis. Baseline correction was effectuated at 100ms before stimulus presentation. Data with amplitude greater than ±75mV were considered as artifact and thus removed.

EEG Statistical analysis

ERP data were analysed by computing the mean amplitude over the epoch period. To test the distribution of the effects regions of interest were selected for each modality. Audio ERP were maximal over fronto-central areas and were analyzed at electrodes FC1, FC2, F3, F4, Fz, Cz, C3 and C4.

Visual ERP were mostly located over posterior areas and were (analyzed) evaluated using the following montage Fz, Cz, O1, O2, Oz, PO3 and PO4.

To test our hypothesis concerning attentional effects on early (P1, N1) and late (P2) components, we performed additional ANOVAs for the latency and amplitude of each component. For the P1, the analyses were carried mostly on frontal sites (F3, FC1, FC2, F4, Fz, Cz). For N1 peak detection a time interval of 100ms – 200ms was selected and the analyses were carried on fronto-central electrodes for audio (FC1, FC2, C3, C4, Cz). Accordingly for the N2 again frontal electrodes were used (FC1, FC2, C3, C4, Cz).

Results

Behavioral Data.

Data from all 22 participants were used for behavioral analyses. A repeated measures ANOVA was carried out including modality (audio/visual) and meter (4 conditions) as factors. There was no interaction between meter and modality (p= 0.5) which implied that the effect of meter (the four conditions) on the reaction times (RTs) can be considered the same for both the auditory and visual modalities. However there was a significant effect of meter for both modalities (for auditory $F(3, 51) = 28.67$, $p<.000$ and for visual $F(3,48)= 50.29$, $p<.000$). Post-hoc analysis showed that for auditory modality RTs for condition 1 were significantly faster from all other conditions, but especially from 2 and 3 (cond1-cond2 p=.0001, cond1-cond3 p=.0001 and cond1-cond4 p=.006). The same was found for the RTs in the visual modality (cond1-cond2 p=.0001, cond1-cond3 p=.0001 and cond1-con4 p=.003). Additionally difference between condition 2 and 3 was not significant for both modalities. (Figure 4)

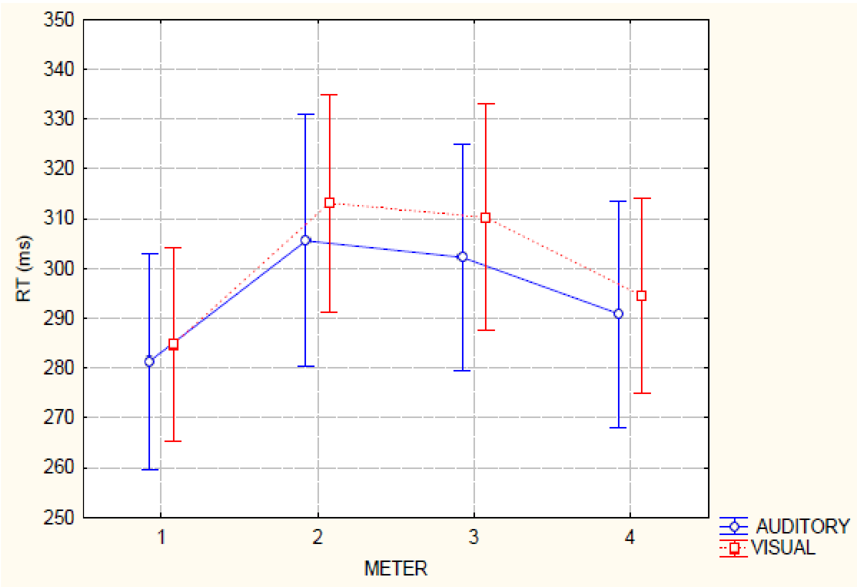

Figure 4. Influence of the meter on reaction times for both modalities, confidence interval 0,95

The fact that RTs for condition 4 were approaching those for condition 1 led us to consider that the strong beat acts as an attractor. Indeed these two conditions are very close in the temporal proximity of the measure (around 250ms). Therefore it might be the case that due to such a temporal proximity, condition 4 benefits of the attentional ascent and/or motor entrainment of condition 1, namely the strong beat. Based on this, for ERP analysis we decided to group together condition 1 & condition 4 and condition 2 & condition 3 so as to amplify the emergence of the effects.

Event-Related Potentials/Electrophysiological data

Data of 5 participants for the visual and 2 for the auditory were rejected due to artifacts during the recording. So, only 17 were retained for the visual part and 20 for the auditory one.

ERPs to audio stimuli

An ANOVA was conducted to assess the effects of three factors namely, meter (4), electrodes (5) and force (strong and weak beats). The last factor, named force is obtained after grouping in pairs condition 1 & condition 4 and condition 2 & condition 3. The audio task used in this experiment elicited several components. Figure 5 displays the typical components P1, N1, P2, N2, P3 as captured at the central electrode Cz for all the four conditions. As can be observed metronome modulated the amplitude of early components P1, N1 and the latency of late component N2.

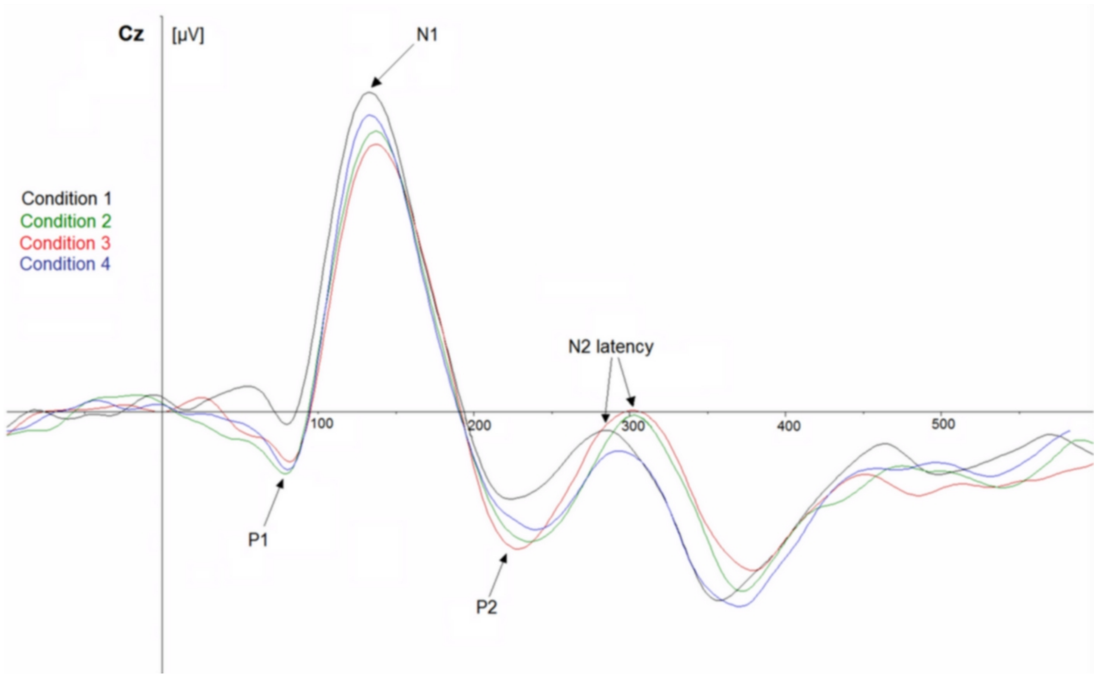

Figure 5. ERP waveforms (negative plotted upward) for all conditions during the auditory task as recorded at the central electrode Cz

P1. Statistical analyses for the mean P1 showed an early effect at around 80ms with attenuated amplitude for the strong condition (Cond1 < Cond2, Cond3, Cond4), $F(5, 95)=5.65$, $p=.0001$, (Figure 5, 6).

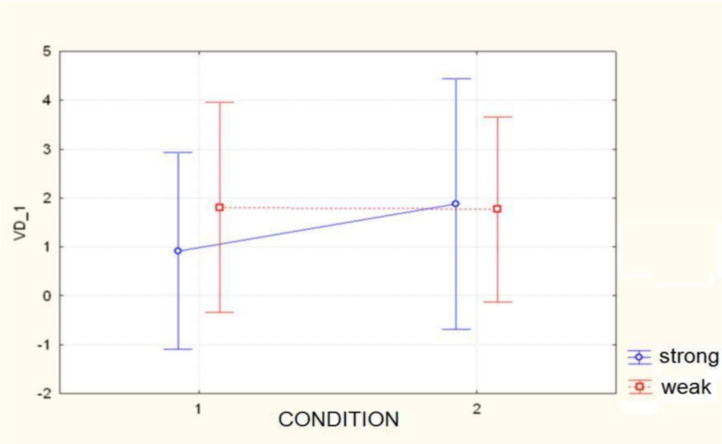

Figure 6. Significant interaction of condition and force factors for P1

*N1***.** Activity of N1 was maximal over five fronto-central electrodes (see Figure 7) at around 134ms and after conditions grouping we obtained a significant effect of metronome, giving a greater amplitude for the strong beats (Cond 1 + Cond 4 > Cond 2 + Cond 3, $F(1, 17)=12.11$, $p=.002$).

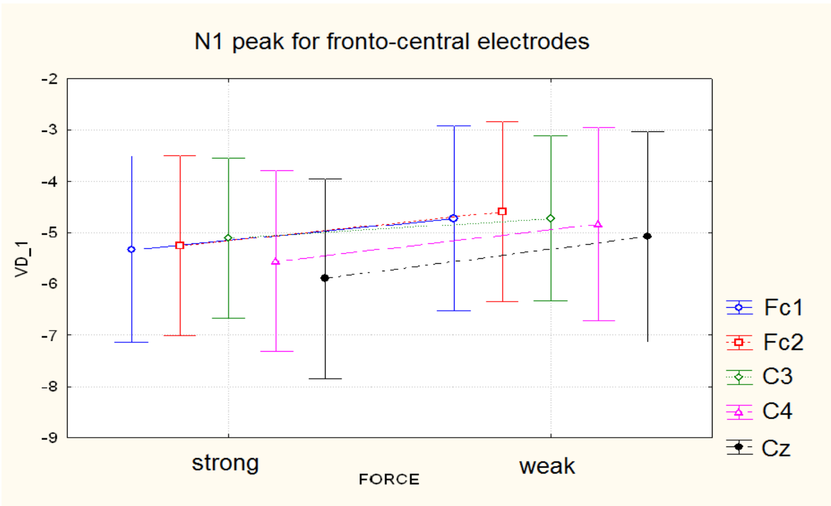

Figure 7. Enhanced N1 amplitude over selected electrodes for strong and weak beats

P2. P2 like P1 was significantly attenuated for Cond1 $F(3, 57)=3.01$, $p=.03$. (Figure 8)

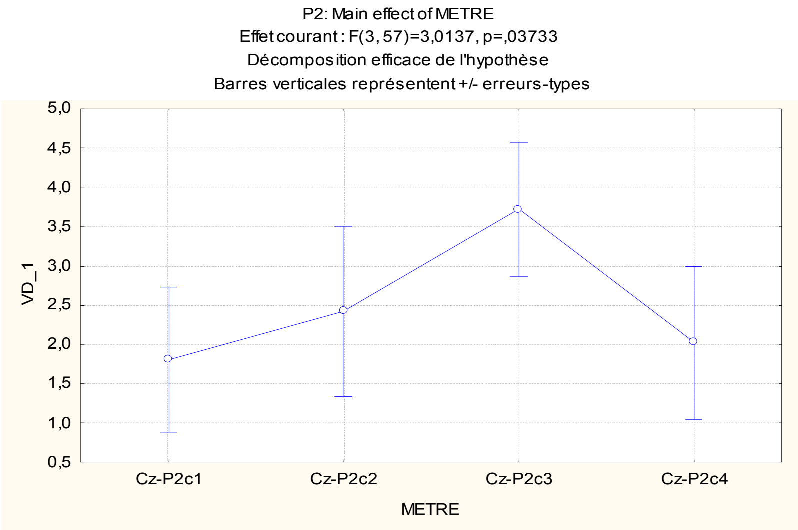

Figure 8. Main effect of meter over P2

N2. The ANOVA on N270 latency (over FC1, FC2, C3, C4, Cz) showed a significant effect of metronome, $F(1, 16)=4.94$, $p=.04$. This effect is owed to condition 2 and 3 which display a retarded peak for this component in comparison to the other conditions 1 and 4 (Figure 9).

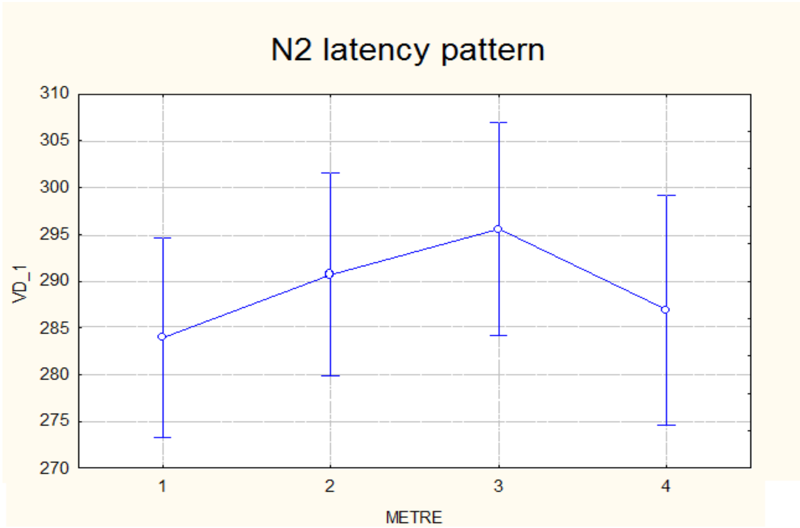

Figure 9. Effect of metronome concerning the latency of N270 in the four conditions

Discussion

The aim of the present experiment was to investigate whether listening to a metronome affects perception and motor preparation via attentional entrainment. At this aim we run an experiment wherein subjects had to perform a speeded response audio and visual detection while they were listening to a metronome. The instances in time used to present stimuli were manipulated in such a way to co-occur with notes having different levels in the hierarchy of the musical metrical structure (going from very strong to very weak level). The behavioral results of the study showed an attentional effect with a faster reaction time. Indeed, subjects responded faster to stimuli that appeared simultaneously to a strong beat in the meter than to stimuli that appeared simultaneously to a weaker position in the metrical hierarchy. Electophysiological data precise behavioral results showing that musical meter influences the amplitude and latency of components P1, N1 and N2.

Component P1 is traditionally linked to visual processing and very few studies on temporal attention have observed it so far (Correa 2005, Correa 2006). Precisely, valid targets enhance P1 amplitude comparing to invalid ones over the occipital sites meaning that expectations are formed that enable more efficient visual perception at the expected moments. Nevertheless it remains unclear how P1 is affected on temporal attention task. In this experiment we found that P1 amplitude was attenuated.

ERP traces differ in early component N1 showing a larger amplitude for condition 1 in comparison to the other conditions. Modulation of N1 amplitudes is related to re-orientating of attention in space and time (Griffin 2001, Lange 2003, Doherty 2005, Correa 2008), for either visual or auditory stimuli. Implicit or explicit cues modify expectancy, orienting attention to a precise spatial or temporal point and resulting in modulated N1 amplitude for attended than unattended stimuli. However N1 amplitude is not consistently modulated by temporal orienting of attention. Several studies have found N1 enhancement (Griffin 2002, Lange 2003 and Correa & Nobre 2008) but some others found no effect (Miniussi 1999, Correa 2005) or Doherty (2005) that observed attenuation. This inconsistency led Correa to the general conclusion that a perceptually demanding task may be critical factor (Correa 2006) to observe early effects. Now, Large and Jones' model for meter perception predicts a maximal level of attention for the strong beat (condition 1), this is rather similar to saying that stimuli co-occuring with strong beats are more expected than those co-occuring with weaker beats. To this extent, the greater amplitude of the early component N1 in condition 1 and condition 4 can be interpreted in a similar manner to the greater amplitude for attended events described in literature. However in the present study the innovative points are that attentional modulation is cross-modal, implicitly induced and obtained with a simple detection task, not demanding in perceptual processing. Additionally in our study N1 activity reflected auditory processing as illustrated in Figure 10.

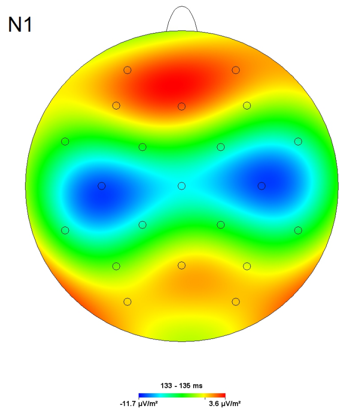

Figure 10. Topography of N1 shows activity distributed over bilateral auditory cortex

Another negativity, the N2 showed to be sensitive to metrical structure, giving an earlier peak for condion 1 and 4 comparing to the other weaker conditions 2 and 3. N2 amplitude attenuation due to temporal expectation was firstly observed in Miniussi 1999. Since then several studies (Griffin 2002, Lange 2003, Correa 2005, Dohertry 2005, Correa 2008) replicated the same results showing that an enhancement of N2 amplitude occurs when expectation conflicts with actual occurrence target. Also, N2 amplitude modulation being a late component reflects motor preparation. However N2 latency modulation has not been observed as much. Recent experiments of Correa 2008 have observed this effect and like P300 seems to be characteristic of temporal orienting studies. According to this study valid targets elicited N2 peak earlier comparing to invalid ones. In our study there are no invalid targets but due to attentional entrainment we have points in time where occurrence of a target is more expected and others points where it is less expected (points where attention is more accentuated). Thus, a stimuli far from the strong beat might create a conflict between the mostly expected temporal occurrence (strong beat) and their actual presentation which in turn causes modulation of N2 latency. This is also supported from the topographic map of the N2 as shown in Figure 10, where activity is distributed over the left motor cortex which is expected given the fact that subjects responded using their right hand. Moreover, if we compare RTs pattern for the behavioral part (Figure 4) and N2 latency pattern (Figure 9), they are similar meaning that earlier peaks for N2 are reflected on quicker manual responses.

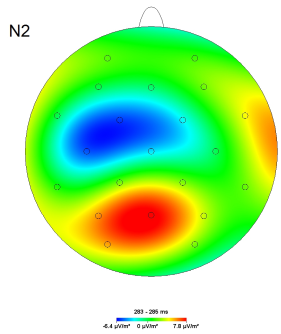

Figure 11. Topography of N2 shows activity over the left motor cortex

Conclusion

Overall the results of the present experiment are valuable from many aspects. First they validate Jones model providing evidence that metrical hierarchy influences level of attention, which in turn affects performance. Most importantly the attentional effects that were obtained in an implicit manner, were not limited to audition, but extended to vision thus producing a cross-modal effect. Regarding the perceptual and motor processing, the metrical structure of a metronome influences the early processing (P1, N1) and motor preparation (N2). Modulation of early components was not expected since existing studies with detection tasks have mainly found that temporal orienting of attention affects late components related to motor preparation. To conclude, the present study showed that musical meter allows to implicitly modify in a fine manner orienting of attention in time.

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