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Electrophysiological evidence of temporal preparation driven by rhythms in audition

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ABSTRACT

Reaction speed to respond to an auditory target stimulus is enhanced when it is presented at a moment matching the temporal structure of a preceding regular rhythm (Sanabria et al., 2011). However, the electrophysiological correlates of this behavioural enhancement remain unknown. In the present study, participants' performed a simple auditory reaction time task in which a regular rhythm with either a fast (400 ms interval between the tones making the rhythm) or a slow (900 ms interval between the tones making the rhythm) was presented prior to the target. The target tone could be presented, with the same probability, 400 ms or 900 ms after the offset of the rhythmic sequence. The behavioural results showed that the fastest responses were obtained when the target appeared in synchrony with the preceding rhythm (e.g., the target was presented 900 ms after the slow rhythm). This behavioural benefit was accompanied by amplitude modulations of the N1 potential and the P2 potential, both related to the processing of the auditory target. Crucially, these electrophysiological modulations were obtained in both the fast and the slow rhythm conditions. The current research demonstrates that rhythms with different paces can drive temporal preparation exogenously, affecting early and late stages of auditory neural processing.

1. Introduction

Temporal regularities of the environment have probably promoted the evolution of cognitive skills such as temporal preparation. Temporal preparation can be defined as the ability to enhance cognitive processing in anticipation of the moment of occurrence of a relevant stimulus, optimizing the processing of that stimulus when it actually occurs (see Nobre et al., 2007, for a review). Empirical evidence shows that temporal preparation can be triggered by regular rhythms, that is, the isochronous presentation of a stimulus sequence. For example, a stimulus onset matching the timing of an auditory regular rhythm is discriminated better than a stimulus preceded by an irregular rhythm (Barnes and Jones, 2000; Jones et al., 2002). Recent studies have further shown that the effect of temporal preparation guided by rhythms generalizes to the visual modality and other behavioural measures such as RT (Correa and Nobre, 2008; Doherty et al., 2005) and that the effect is not constrained to a single rhythmic pace and temporal interval (Sanabria et al., 2011).

In Sanabria et al.'s (2011; Experiment 3) study we presented regular rhythms at two different paces manipulated on a trial-by-trial basis. The fast rhythm consisted of the presentation of a sequence of six tones separated by intervals of 400 ms, whereas the slow rhythm included a 900-ms interval between tones (see Fig. 1). Each rhythm pace was associated to different foreperiods (200, 400, 900, 1400, and 1600 ms) with equal probability ($p = 0.2$). The results showed that RTs to respond to the auditory target stimulus presented after the rhythm were faster for targets appearing at short foreperiods (200 and 400) when the preceding rhythm was fast rather than slow. On the other hand, RTs were faster for targets appearing at the long foreperiods (900 and 1400) when the preceding rhythm was slow rather than fast. This latter finding was crucial to rule out that our effects were just due to higher arousing properties of fast vs. slow rhythms. This study suggests that auditory RT performance is fastest for targets appearing at the foreperiod matching the pace of a regular rhythm.

The above behavioural studies have consistently supported that regular rhythms can enhance both speed and accuracy of task performance. Sanabria et al. (2011) went a step further by showing that temporal preparation guided by rhythms depended on the particular temporal matching between the rhythmic pace and the moment of target appearance, and not simply on the temporal regularity of the rhythm. However, the neural correlates of such RT behavioural improvement remain unknown. The aim of the present research was to study the electrophysiological correlates

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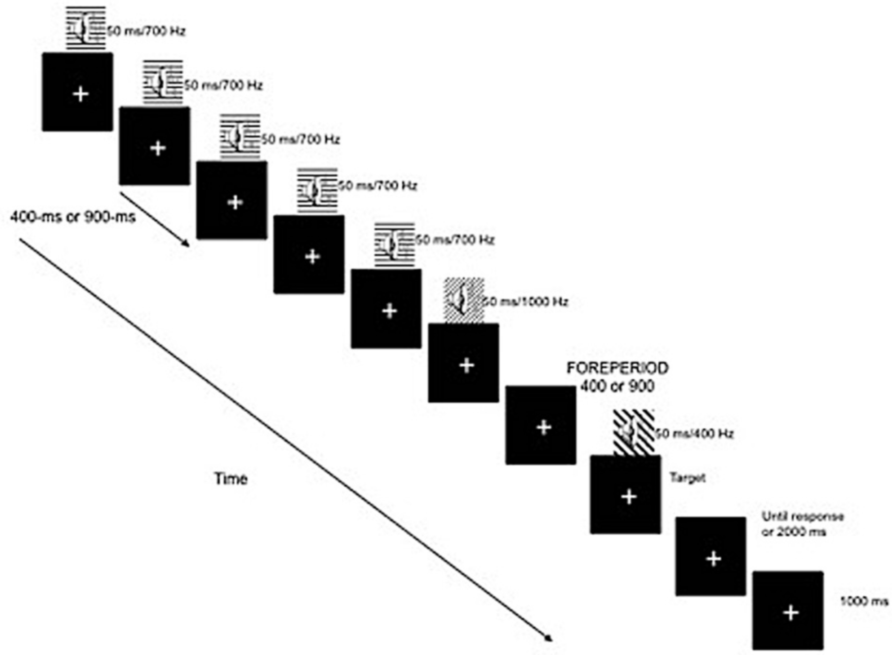

Fig. 1. Schematic illustration of a trial.

of temporal preparation guided by two rhythms of different paces, specifically in the auditory modality.

When compared to irregular rhythms, regular rhythms seem to facilitate later stages of cognitive processing as indexed by an enhancement of the P3 event-related potential (ERP) linked to the target onset (Lange, 2009, 2010; Schmidt-Kassow et al., 2009; Schwartze et al., 2011). Regarding early auditory processing, one could expect regular rhythms to enhance the N1 potential, an ERP peaking around 100 ms after an auditory stimulus with a central distribution over the scalp, generated in the primary and secondary auditory cortices (Näätänen and Picton, 1987). In effect, the amplitude of the auditory N1 is increased for expected vs. unexpected target onsets in temporal-orienting studies, where symbolic temporal cues are used to indicate the most probable moment of target appearance (Lampar and Lange, 2011). However, the scarce evidence regarding the effect of temporal preparation induced by rhythms on the auditory N1 reveals a different pattern of results.

Lange (2009) investigated the effect of rhythms on the auditory N1 potential by asking participants to detect a 10-ms silent gap that was present in a small proportion of the auditory targets. The target could be preceded by either a regular or irregular rhythm, which consisted of a sequence of 12 tones inter-separated by an interval that was fixed (550 ms) or variable (random durations between 300 and 800 ms), respectively. The rhythm was followed by a constant foreperiod of 1650 ms (matching three steps of the 550-ms rhythm), and then the target appeared. The results of two experiments consistently showed that the regular rhythm attenuated the N1 amplitude as compared to the irregular rhythm. Lange's results were consistent with the findings of an earlier study by Schafer et al. (1981; see also Costa-Faidella et al., 2011). These authors reported an attenuated amplitude and earlier latency of the auditory N1, P2, N2 and P3 potentials when the target tone was presented after a regular sequence of visual events, compared to a condition in which the visual events formed a temporally irregular sequence.

In a subsequent experiment, Lange (2010) further tested whether the N1 attenuation effect was driven by temporal preparation. In contrast to her previous experiment (and to Schafer et al.'s 1981, study) where the foreperiod was constant and therefore predictable, the foreperiod duration was variable such that the target could appear after either 800, 1100 or 1400 ms. The N1 attenuation was mainly expected in the 1100-ms condition, as this was the only foreperiod matching (two steps of) the 550-ms regular rhythm. However, in contrast to her previous study, the results showed that the amplitude of the N1 elicited by the target was increased following regular as compared to irregular sequence of tones (this effect was restricted to the left hemisphere). Moreover, the foreperiod manipulation (different durations with a similar a priori probability that changed trial-by-trial) led to decreased RTs and enhanced N1 amplitudes on left electrodes with increasing foreperiod durations (i.e., the foreperiod effect; see Niemi and Näätänen, 1981, for a review). Hence, it might be possible that any attenuation of the N1 potential by regular rhythms was not observed in this experiment because it was masked by the enhancement produced by the foreperiod effect. In fact, interactions between the effects of regular rhythms and foreperiod duration have been reported in the visual modality (Correa and Nobre, 2008; Rohenkohl et al., 2011).

Two main issues motivated the present research. First, to the best of our knowledge, there are not ERP studies investigating the effect of regular rhythms with different paces on auditory target processing, since previous studies have always compared the effect of an isochronous regular with the effect of an irregular rhythm. In the present study, the auditory target was presented after a time interval that could match or mismatch the rhythmic pace of the preceding regular rhythm. That way, we were able to investigate whether the effect of a regular rhythm on auditory target ERPs in a simple RT task depended on the temporal matching between the particular rhythmic pace and the elapsed time prior to the onset of the target, or simply on the temporal regularity of the rhythm. Second, the scarce extant ERP evidence does not make clear the nature of the effect of regular rhythms on auditory processing.

In order to achieve our purpose, we designed an experiment with the following main manipulations. As in our previous research (Sanabria et al., 2011), temporal preparation was induced by a regular rhythm of either a fast or a slow pace. In the current simpler design, only two foreperiods were used so that the target tone could appear at either a short (400 ms) or long (900 ms) foreperiod. Since rhythm paces and foreperiods were paired at 50%, temporal expectations would emerge automatically from the rhythm itself rather