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Mechanisms of implicit timing: Cognitive and electrophysiological manifestations of temporal expectations following rhythmic visual input

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Abstract

Temporal processing is frequently performed implicitly, when temporal calculations are required in order to perform a task, whose output is not temporal in essence. One prevalent use of implicit timing is in the formation of temporal expectations, in which the timing of an upcoming event is predicted in order to prepare for its occurrence. The sources of this prediction can be "endogenous", relying on memorizing the temporal interval between the expected event and a preceding reference event, measuring the time from the onset of the reference, and increasing preparedness when the expected interval elapses. However, temporal expectations can also be "exogenous", namely based on extracting temporal information from the ongoing temporal dynamics of the input, rather than memory-dependent. One unique case of such temporal dynamics is when the input is isochronous (i.e., stimuli appear rhythmically, with fixed inter-onset-interval), such as in biological motion, speech, or music. Based on findings from auditory rhythms, it has been suggested that in such case, expectations are realized by synchronization of internal oscillators to the input periodicity, a process that encompasses both the representation of the interval and the application of expectation at the correct time. In two studies, we investigate temporal expectations created in visual rhythmic context, showing that they have unique cognitive and electrophysiological characteristics, and dissociating them from other types of temporal expectations.

The first study establishes that exposure to rhythmic input is sufficient to form temporal expectations unintentionally, and dissociates them from intentional expectations. Targets were presented either in-phase or out-of-phase with rhythmically flickering coloured stimuli, in three conditions: 1. the rhythm was non-predictive; 2. the rhythm was non-predictive and temporal expectations were concurrently manipulated in a memory-based fashion using predictive colour cues; 3. the rhythm was predictive and intentionally used to form expectations. We found that even when expectations were intentionally based on colour cues, and reliance on the rhythm could be counter-productive, there was significant facilitation for targets that appeared

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incidentally in-phase with the rhythm. This modulation combined additively with the validity effect of colour. Congruently, the contingent negative variation (CNV), an EEG component present during target anticipation, was driven by the interval of the rhythm even when the rhythm was non-predictive. When intentionally using the rhythm to form expectations, the behavioural modulation was stronger. Additionally there was also modulation of the latency of the P3, a target-evoked EEG component related to stimulus evaluation, as well as desynchronization of pre-target alpha-band oscillations. Thus, the unintentional rhythmic temporal expectations are dissociated from both intentional rhythmic expectations and memory-based expectations.

The second study examines whether intentional formation of rhythmic expectations involves more than application of endogenous expectations following learning of the repeating fixed interval in the rhythm. For this purpose, we compared behaviour and EEG activity in three conditions: 1. stimuli appeared a-rhythmically followed by the target; 2. stimuli appeared rhythmically followed by the target; 3. pairs of stimuli (S1, S2) were presented with a fixed interval within pair and a random interval between pairs with the second stimulus in the last pair being the target. In the latter two conditions, in most of the trials the target appeared at the cued interval (valid cue) and in few trials it appeared at a different interval (invalid). Reaction times were not different between predictive conditions for valid trials, but the validity effect was larger for rhythmic than for repeated interval condition. Concordantly, the CNV peak amplitudes were not different between predictive conditions. However, when targets were expected at the early interval but were omitted, the CNV remained at peak amplitude in the repeated interval condition, but returned to baseline in the rhythmic condition. Assuming that the CNV reflects the level of preparation, this implies that there is more focus in time around the expected time point in the rhythmic condition. Unlike the CNV, modulations of the P3 latency and desynchronization of pre-target alpha-band oscillations did not differ between rhythmic and repeated interval conditions. Thus, rhythmic expectations are unique in being more temporally accurate and more difficult to disengage from than memory-based expectations, and this effect is manifested in anticipatory activity rather than in post-target responses.

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Keywords: Temporal expectations; Regularity extraction; Automaticity; Attention; EEG;