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Temporal orienting of attention is interfered by concurrent working memory updating

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ABSTRACT

A previous dual-task study (Capizzi, Sanabria, & Correa, 2012) showed that temporal orienting of attention was disrupted by performing a concurrent working memory task, while sequential effects were preserved. Here, we recorded event related potentials (ERPs) during single- and dual-task performance to investigate how this behavioural dissociation would be expressed in neural activity measures. The single-task condition required participants to respond to a visual target stimulus that could be anticipated on the basis of a highly predictive temporal cue. The dual-task condition introduced a concurrent working memory task, in which colour information had to be updated on every trial. The behavioural results replicated our previous findings of impaired temporal orienting, but preserved sequential effects, under dual-task relative to single-task conditions. The ERPs results showed that temporal orienting and sequential effects both modulated the cue-locked preparatory contingent negative variation (CNV) and the target-locked *N*2 amplitude and *P*3 latency under single-task, but not under dual-task conditions. In contrast to temporal orienting, sequential effects were also observed at the early target-locked *P*1 and *N*1 potentials. Crucially, only the *P*1 modulation survived dual-task interference. These findings provide novel electrophysiological evidence that performance of a concurrent working memory task may interfere in a selective way with neural activity specifically linked to temporal orienting of attention.

1. Introduction

Temporal expectancies are critical in many of our everyday activities such as driving, playing sport or music (Nobre, Correa, & Coull, 2007). In soccer, for example, anticipating the goalkeeper's movements before kicking the penalty may determine the success or failure of the kicker when choosing the direction of the shot (Núñez, Oña, Raya, & Bilbao, 2009).

In laboratory settings, temporal expectancies have been widely investigated through a temporal variant of Posner's spatial orienting task (Posner, Snyder, & Davidson, 1980). In a typical temporal orienting task (Correa, 2010; Coull & Nobre, 1998; Nobre, 2001), participants have to respond to the onset of a target stimulus. Before the target is presented, a symbolic cue indicates whether the target is likely to appear early (e.g., after 1000 ms) or late (e.g., after 2000 ms). On a large proportion of trials (e.g., 0.75), the cue is valid so that participants are encouraged to use it in order to anticipate the subsequent target onset (valid condition). On the remaining trials, the target appears either earlier or later than expected (invalid condition). Results typically show faster and more accurate responses for targets occurring at early validly cued temporal intervals as compared to earlier than expected late targets, i.e., the so-called "validity effects". At the long time interval, validity effects are usually smaller or even absent because if the target does not appear shortly as predicted by the early cue, participants infer that it would appear later, which enables them to re-orient their attention to the late moment (e.g., Correa, Lupiáñez, Milliken, & Tudela, 2004; Coull & Nobre, 1998; Karlin, 1959).

Participants' reaction time (RT) in temporal orienting tasks is affected not only by the predictive information given by the cue, but also by the duration of the cue-target interval (i.e., foreperiod) that was used on the previous trial. Namely, for current short time intervals, participants' RTs are typically faster if the previous interval was short as compared to when it was long, a phenomenon known as "sequential effects" (e.g., Drazin, 1961; Los & Van den Heuvel, 2001; Steinborn, Rolke, Bratzke, &Ulrich, 2008; Vallesi & Shallice, 2007; Woodrow, 1914). Sequential effects are usually asymmetric since for current long time intervals, participants' RTs are fast independently of whether the previous interval was short or long.

Los' "trace-conditioning" model (Los, 1996; Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001) proposes that sequential

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effects would reflect the operation of a single automatic mechanism, unintentionally driven by stimulus sequence association from one trial to the next rather than by internal volitional expectations. According to the "dual-process" model proposed by Vallesi and collaborators (Vallesi, 2010; Vallesi & Shallice, 2007; Vallesi, Shallice, & Walsh, 2007), sequential effects would be instead the outcome of two processes: automatic arousal modulation by the previous interval, and voluntary preparation triggered by the conditional probability of target appearance over time (i.e., if the target did not occur at the short interval, the probability that it will occur at the long interval grows as a function of the elapsed time; see Coull, 2009; Niemi, & Näätänen, 1981, for reviews). That is, a previous long interval would decrease participants' arousal, while a previous short interval would increase arousal levels, thus lengthening or speeding up RT, respectively. The arousal effect would occur regardless of the duration of the current interval, giving rise to symmetric sequential effects. The observed asymmetry would be instead determined by the controlled process computing the conditional probability of target appearance on the longest trials, with the result of counteracting the negative effect on RT of a previous (less arousing) long interval.

Despite the differences between the two models described above, a general consensus exists on the idea that sequential effects and temporal orienting would be mediated by dissociable cognitive and neural mechanisms. Los and Van den Heuvel (2001), for example, showed that sequential effects were stronger outside the attentional 'focus' of temporal orienting (i.e., on invalid conditions rather than on valid ones). Other authors have reported that temporal orienting effects could be elicited independently of sequential effects (Correa et al., 2004; Correa, Lupiáñez, & Tudela, 2006). This behavioural evidence is consistent with recent neuropsychological research showing that temporal orienting effects, triggered by symbolic cues, were diminished in patients with right prefrontal lesions relative to performance of control participants, whereas sequential effects were preserved (Triviño, Arnedo, Lupiáñez, Chirivella, & Correa, 2011; Triviño, Correa, Arnedo, & Lupiáñez, 2010).

The neural substrates underlying temporal orienting effects have been widely investigated using event related potential (ERP) measures (e.g., Correa & Nobre, 2008; Correa, Lupiáñez, Madrid, & Tudela, 2006; Doherty, Rao, Mesulam, & Nobre, 2005; Griffin, Miniussi, & Nobre, 2002; Lampar & Lange, 2011; Lange, 2012; Miniussi, Wilding, Coull, & Nobre, 1999; Sanders & Astheimer, 2008). Three major ERPs have been often associated to temporal orienting, namely, the contingent negative variation (CNV), the *N*2 and the *P*3. The CNV is a slow negative wave occurring during the preparatory interval between a warning signal and an impending stimulus that requires a response (Walter, Cooper, Aldridge, McCallum, & Winter, 1964). The development of the CNV is sensitive to the temporal information provided by predictive cues, as demonstrated by enhanced negativity following an early expectancy cue in relation to a late expectancy cue at the moment of likely early target onset (Los & Heslenfeld, 2005; Loveless & Sandford, 1974; Miniussi et al., 1999; Trillenberg, Verleger, Wascher, Wauschkuhn, & Wessel, 2000). This finding shows that temporal orienting may increase participant's readiness to respond around the time of the expected event.

Temporal orienting also modulates brain potentials linked to cognitive control and motor response, such as the *N*2 and the *P*3 (see Folstein & Van Petten, 2008; Polich, 2007, for reviews on the *N*2 and *P*3 potentials, respectively). The *N*2 amplitude is attenuated and the *P*3 latency is reduced for expected, validly cued, targets as compared to unexpected, invalidly cued, targets (Correa & Nobre, 2008; Correa et al., 2006; Doherty et al., 2005; Griffin et al., 2002). The *N*2 attenuation may reflect "the temporal maintenance of response inhibition to prevent responding at inappropriate times" (Correa & Nobre, 2008, p. 1654), while the reduced *P*3 latency would reflect the synchronization and preparation of fast responses to the upcoming event (Griffin et al., 2002; Miniussi et al., 1999). Alternatively, no modulation of early visual processing stages, indexed by the *P*1 and *N*1 potentials, is usually observed for targets presented at the expected moment in time, at least when the task does not involve high discriminative demands (see Correa, 2010; Correa et al., 2006, for reviews).

In contrast to temporal orienting, little attention has been paid to the neural correlates of sequential effects as well as to the interrelations between temporal orienting and sequential effects. A noticeable exception is the electrophysiological study by Los and Heslenfeld (2005) (see also Van der Lubbe, Los, Jáskowski, & Verleger, 2004). The authors followed a temporal orienting procedure, in which the cue conveyed either no information (neutral condition) or valid information (valid condition) about the possible moment (early versus late) of target onset. The CNV was measured as an index of temporal preparation. They found that the CNV amplitude was more negative before an early target onset when the previous interval had been short rather than long on both neutral and valid conditions. Interestingly, this effect by the previous interval was not eliminated at the early moment even when participants had been validly cued to a late target onset. That is, the contribution of sequential effects on the modulation of the CNV was additive to that of temporal orienting, which confirmed that sequential effects may contribute to the development of temporal preparation independently of temporal orienting.

Unfortunately, however, Los and Heslenfeld (2005) only measured brain activity related to the warning (cue) signal, while ERPs associated to target processing were not taken into account, thus precluding a direct comparison between the consequences of temporal orienting and sequential effects on stimulus analysis. To the best of our knowledge, sequential effects of temporal preparation over target processing have not been previously investigated with measures of brain activity.

In the present study, we explored the electrophysiological correlates of both temporal orienting and sequential effects in a dual-task experiment. The starting point of this work was a behavioural study (Capizzi et al., 2012), in which we tested the controlled versus the automatic nature of temporal orienting and sequential effects (cf. Logan, 1979; Posner & Snyder, 1975). In our study, participants performed the temporal orienting task either alone (single-task condition) or simultaneously with a working memory updating task (dual-task condition). In the single-task condition, a coloured cue (a short versus a long line) predicted on a trial-by-trial basis the most likely moment of target onset to which participants had to respond. In the dual-task condition, working memory demands were manipulated by instructing participants to mentally update and report the final count of temporal cue colours at the end of each block.

The use of concurrent updating representations in working memory as secondary task was motivated by two main findings. First, dual-task studies that employed a working memory task have shown interference between working memory and time estimation of intervals in the range of seconds, which suggests that these two tasks may compete for common executive resources (e.g., Brown, 2006; Fortin & Breton, 1995). Second, working memory and timing tasks additionally share prefrontal structures (see Lewis & Miall, 2006, for a review), which are also related to temporal orienting of attention (Triviño et al., 2010, 2011). Hence, our premise was that the introduction of a concurrent working memory task would interfere selectively with the timing processes underlying controlled temporal preparation (i.e., temporal orienting effects), while leaving the automatic component (i.e., sequential effects) unaffected. Consistent with