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PROCESOS AUTOMÁTICOS Y CONTROLADOS DE LA PREPARACIÓN TEMPORAL

DOCTORANDA

MARIAGRAZIA CAPIZZI

DIRECTORES

DANIEL SANABRIA LUCENA Y ÁNGEL CORREA TORRES

DEPARTAMENTO DE PSICOLOGÍA EXPERIMENTAL

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UNIVERSIDAD DE GRANADA

Universidad de Granada
Departamento de Psicología Experimental

Campus Universitario de Cartuja, s/n
Telf. +34-958243763 –Fax: +34 -958246239
18071 – Granada (España)

Procesos automáticos y controlados de la preparación temporal

Tesis Doctoral presentada por **Mariagrazia Capizzi** en el *Departamento de Psicología Experimental* para aspirar al grado de Doctora en Psicología, en el Programa de *Doctorado en Psicología* de la Universidad de Granada. En este trabajo se han respetado las pautas que establece la normativa de la Universidad de Granada para la obtención del título de Doctorado Internacional.

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Fdo. Mariagrazia Capizzi	Fdo.: Ángel Correa Torres

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Chapter I: Resumen en español

Múltiples actividades de nuestra vida diaria, como por ejemplo practicar un deporte, bailar, tocar un instrumento o respetar el orden en un turno de conversación, requieren la capacidad de usar la información temporal que nos proporciona el entorno para optimizar nuestra conducta. Esta capacidad se define como "*preparación temporal*". A lo largo de los últimos años, un amplio número de estudios empíricos (véase Correa, 2010; Nobre, Correa, & Coull, 2007, para una revisión) ha demostrado la existencia de diferentes mecanismos a través de los cuales es posible alcanzar un nivel óptimo de preparación temporal. No obstante, aún no se ha determinado cuál es la naturaleza de los procesos cognitivos y neurales implicados en la preparación temporal y, más concretamente, cuál es el papel que los procesos *automáticos* y *controlados* juegan en el desarrollo de dicha habilidad cognitiva.

El objetivo principal de la tesis es profundizar en la distinción entre los procesos automáticos y controlados que intervienen en el desarrollo de la preparación temporal. Por ello, nos centramos en el estudio de dos efectos de preparación temporal, el "*efecto de orientación de la atención en el tiempo*" y los "*efectos secuenciales*". El primer efecto hace referencia a la capacidad de los participantes de prepararse para el instante específico en que se anticipa la ocurrencia futura de un evento por medio de señales temporales predictivas (Correa, 2010; Nobre, 2001; Coull & Nobre, 1998). Los efectos secuenciales son los efectos debidos al orden de presentación de los diferentes intervalos de tiempo empleados en una tarea de preparación temporal. Ambos efectos se pueden medir en el paradigma de "orientación de la atención en el tiempo" que fue previamente propuesto por Nobre y colaboradores (Nobre, 2001; Coull & Nobre, 2008). El procedimiento consiste en presentar una señal predictiva simbólica (e.g., una línea *corta* que significa *pronto* y una línea *larga* que significa *tarde*) que indica si el estímulo objetivo, al cual se tiene que contestar, aparecerá tras un intervalo corto o tras un intervalo largo de tiempo. Lo que se manipula es la validez de la señal, por lo cual el estímulo puede aparecer en el intervalo indicado por la señal en el 75% de los casos (ensayos válidos), mientras que en los ensayos restantes el estímulo puede aparecer en el intervalo no señalado (ensayos inválidos). Los resultados típicamente muestran un descenso en el tiempo de reacción (TR) cuando los estímulos aparecen en los intervalos indicados por la señal temporal en comparación con aquellos que son erróneamente señalizados. Esa diferencia en el TR entre ensayos válidos e inválidos se define como efecto de orientación de la atención en el tiempo. Sin embargo, este paradigma nos permite estudiar también cómo se desarrolla la preparación temporal en función de la información proporcionada por la duración del intervalo del ensayo previo. Es decir, el TR en el ensayo actual es más lento cuando el intervalo anterior es de duración larga en vez de corta. Este fenómeno se conoce en la literatura como efectos secuenciales (e.g., Drazin, 1961; Los & Van den Heuvel, 2001; Steinborn, Rolke, Bratzke, &Ulrich, 2008; Vallesi & Shallice, 2007; Woodrow, 1914). Los efectos secuenciales son generalmente asimétricos, ya que se observa un coste en el TR cuando el ensayo actual es más corto que el anterior; sin embargo no se observa coste en TR cuando el intervalo actual es más largo.

Existen diferentes perspectivas desde las que se intenta explicar cómo se generan los efectos secuenciales en una tarea de preparación temporal. La “teoría de condicionamiento de huella” (Los, 1996; Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001) plantea que lo efectos secuenciales reflejan un proceso automático de condicionamiento entre la señal temporal y el estímulo objetivo. Opuestamente, según la “teoría del procesamiento dual” (Vallesi, 2010; Vallesi & Shallice, 2007; Vallesi, Shallice, & Walsh, 2007), los efectos secuenciales se deben tanto a un proceso automático, basado en la modulación de la alerta motora producida por el ensayo previo, como a un proceso controlado, que depende del cómputo de probabilidades de aparición de los estímulos objetivo. En concreto, si el ensayo previo fue largo el estado de alerta del participante es bajo, así que aumenta el TR, mientras que si el ensayo previo fue corto el nivel de alerta del participante es alto lo cual disminuye el TR. Este efecto de alerta es más pronunciado cuando los ensayos actuales son cortos en vez de largos explicando la asimetría de los efectos secuenciales. En los ensayos actuales largos los TR son siempre rápidos porque si el estímulo objetivo no aparece después del intervalo corto, es cierto que aparecerá tras un intervalo largo (*efecto de foreperiod*; véase Coull, 2009; Niemi, & Näätänen, 1981). Aunque no existe un acuerdo claro entre estos dos modelos respecto a la naturaleza del mecanismo implicado en los efectos secuenciales, estudios previos han demostrado una clara disociación entre los efectos secuenciales y el efecto de orientación de la atención en el tiempo (Correa et al., 2004; Correa, Lupiañez, & Tudela, 2006; Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001). Por ejemplo, el efecto de orientación de la atención en el tiempo mediante señales simbólicas depende de estructuras de control (de la corteza prefrontal derecha), ya que se reduce después una lesión padecida en esta parte del cerebro (Triviño, Correa, Arnedo y Lupiáñez, 2010). Por el contrario, los efectos secuenciales no parecen depender de estructuras prefrontales (Triviño et al., 2010; Vallesi et al., 2007) y, sin embargo, no parece claro cuáles son las bases neurales que dan lugar a estos efectos. Teniendo en cuenta esta disociación neural, la orientación de la atención en el tiempo se ha relacionado con la implicación de procesos de carácter controlado, mientras que los efectos secuenciales con procesos de carácter automático.

Sin embargo, los estudios previos no aportan evidencia directa sobre la naturaleza- automática o controlada- de los dos procesos de preparación temporal mencionados anteriormente. Por ello, diseñamos una primera serie experimental compuesta por tres experimentos conductuales donde se empleó una metodología de tarea dual. El paradigma consistía en la presentación de una tarea principal de orientación de la atención en el tiempo junto con una tarea de memoria de trabajo, para disociar entre el efecto de orientación temporal y los efectos secuenciales. Los resultados mostraron que el efecto de orientación de la atención en el tiempo se vio afectado en la condición de tarea dual en función de las demandas de ambas tareas de preparación temporal y de memoria de trabajo. Por el contrario, los efectos secuenciales no fueron alterados cuando los participantes realizaron la tarea secundaria. Esta investigación demostró que prepararse en el tiempo de forma voluntaria requiere procesos de tipo controlado que compiten por recursos con la tarea de memoria de trabajo (ej., Logan, 1979; Posner & Snyder, 1975). Sin embargo, los efectos secuenciales no mostraron ninguna alteración al realizarse la doble tarea, lo que indica la implicación de procesos de carácter automático.

Ante el hecho de que el efecto de orientación de la atención en el tiempo se vio alterado en la condición de tarea dual, cabe preguntarse cómo y en qué etapa del procesamiento de la información se produjo dicha interferencia entre la tarea de orientación temporal y la tarea de memoria de trabajo. Asimismo, nos preguntamos si los efectos secuenciales modularían del mismo modo que el efecto de orientación de la atención en el tiempo la actividad cerebral relacionada con el procesamiento de los estímulos. Sin embargo, ningún estudio hasta la fecha había analizado los correlatos electrofisiológicos de la modulación ejercida por los efectos secuenciales, mientras numerosos estudios se han centrado en los correlatos del efecto de orientación de la atención en el tiempo (véase Nobre, 2001, para una revisión). Por ello, en la segunda serie experimental de la tesis utilizamos el mismo procedimiento de tarea dual de la primera serie y añadimos medidas de registro electrofisiológico cerebral. De esta forma pretendíamos analizar el curso temporal del efecto de orientación de la atención en el tiempo y de los efectos secuenciales sobre el procesamiento del estímulo objetivo, así como la modulación por parte de la tarea dual. Dada la disociación encontrada a nivel conductual entre los efectos secuenciales y el efecto de orientación de la atención en el tiempo en nuestra primera serie, planteamos la hipótesis de una disociación a nivel de correlatos electrofisiológicos. Los resultados de esta segunda serie replicaron la disociación conductual obtenida entre los efectos secuenciales y el efecto de orientación de la atención en el tiempo. A nivel electrofisiológico nuestros resultados mostraron una interferencia selectiva entre el efecto de orientación de la atención en el tiempo y la tarea secundaria de memoria de trabajo. De forma específica, la tarea secundaria eliminó la modulación ejercida por el efecto de orientación de la atención en el tiempo sobre la variación contingente negativa (CNV), un componente electrofisiológico que ha sido relacionado con procesos intencionales de preparación hacia la ocurrencia inminente de un estímulo (Walter, Cooper, Aldridge, McCallum, & Winter, 1964). Además, solo en la tarea principal de preparación temporal encontramos que el efecto de orientación de la atención en el tiempo influyó sobre componentes asociados con procesos tardíos de decisión y ejecución de respuesta, como N2 y P3, que se han relacionado con el proceso de orientación temporal (Nobre, 2001; Correa et al., 2006). Sin embargo, tanto la modulación de la CNV como dicha modulación del procesamiento tardío producida por la orientación temporal no se encontró al realizar la tarea dual de memoria de trabajo, lo cual apoya la hipótesis de una interferencia selectiva entre la tarea de orientación temporal y la tarea secundaria. Por otro lado, el resultado más crucial consistió en la obtención de los efectos secuenciales en el componente perceptual P1y en el hecho de que esa modulación resistió a la interferencia por parte de la tarea dual. No obstante los efectos secuenciales modularon el procesamiento del estímulo objetivo de la misma manera que el efecto de orientación de la atención en el tiempo tanto en la CNV como en el N2 y el P3 y, más relevante, dicha modulación se vio alterada en la condición de tarea dual.

Los resultados de la segunda serie plantearon la posibilidad de que el proceso automático subyacente a los efectos secuenciales pudo ser modulado por procesos de control. Es decir, cabe la posibilidad de que el hecho de haber utilizado un paradigma de orientación temporal donde los participantes tenían que generar una expectativa explícita al comienzo de cada ensayo pudo haber afectado a las modulaciones ejercidas por la duración del ensayo previo. Para comprobar esta hipótesis, diseñamos la tercera serie experimental donde la señal informativa fue sustituida por una señal neutral donde la señal temporal no requería a los participantes generar una expectativa explícita para contestar al estímulo objetivo. De esta manera pretendíamos reducir los factores de control en el estudio de los correlatos electrofisiológicos de los efectos secuenciales. Los resultados de esta tercera serie confirmaron que los efectos secuenciales pueden modular el procesamiento de los estímulos tanto a nivel temprano (como reflejado en el componente P1) cuanto a nivel tardío (P3). Estos hallazgos presuponen un desafío por los modelos actuales de los efectos secuenciales que explican estos efectos simplemente como una mejoría de la respuesta motora.

En conclusión, la presente tesis aporta nueva evidencia sobre los procesos de la preparación temporal. El conjunto de resultados apuntan a que el efecto de orientación de la atención en el tiempo depende de procesos de control, mientras los efectos secuenciales de procesos de naturaleza automática. Sin embargo, esos procesos automáticos se pueden modular en un contexto de control. Finalmente, podemos concluir que los procesos controlados y automáticos que subyacen a estos efectos de preparación temporal se pueden entender como parte de un mecanismo flexible, que se desarrolla a lo largo de un continuo entre control y automatismo, que nos permite optimizar nuestra conducta.

Chapter II: Introduction

Imagine that your favorite radio show devised an online contest which consists of awarding a prize to the first person who answers a phone quiz question, and that all you need to do is getting ready within the last five minutes before the program ends. Would you be able to pick up the phone on the first ring and be the winner? In other words, do you think you can use this temporal information in advance to speed up your response? If you think you can, you are indeed right. Congratulations on your winning!

The example above illustrates the importance of timing in our everyday life. More specifically, it emphasizes the critical ability to anticipate the occurrence of a forthcoming event in order to optimize performance at the appropriate moment in time. Hereafter, we will refer to this cognitive ability as *temporal preparation* (e.g., Nobre, Correa, & Coull, 2007). From a theoretical point of view, studies on temporal preparation are rooted in the field of time perception, since any ability to use time information certainly relies upon our ability to estimate the passage of time. However, temporal preparation is mainly concerned with the ability to use time information about *when* a relevant event is going to occur rather than with the ability to consciously estimate or reproduce a discrete duration (i.e., time estimation and reproduction tasks, respectively; Grondin, 2010; Ivry & Hazeltine, 1995).

Temporal preparation can be flexibly built up on the basis of different information, such as that provided explicitly by task instructions or afforded implicitly by the task context. As will become clear in the next sections, there is good reason to believe that temporal preparation would be accomplished by multiple rather than a single mechanism. The main goal of the present thesis was to deepen our knowledge in the *controlled* and *automatic* cognitive processes and neural mechanisms underlying temporal preparation. To this end, we focused on two critical behavioural temporal preparation effects, namely, *temporal orienting of attention* and *sequential effects*. The following sections provide an overview of these experimental effects with particular attention being paid to their underlying mechanisms. The Introduction also offers a theoretical background on the basic paradigms used to investigate temporal preparation. The review of this literature will finally lead on to a consideration of the principal issues that have inspired the work of the present thesis.

Temporal preparation: the starting point

One of the most used experimental procedures to measure temporal preparation is the foreperiod paradigm. In a typical foreperiod paradigm, a warning signal and a target stimulus, to which the participant is to make a response, are presented separated by a temporal interval termed “foreperiod” (for reviews, see Coull, 2009; Niemi & Näätänen, 1981). The way by which foreperiod durations are manipulated during the task has a strong impact on participants’ reaction times (RTs). If the foreperiod duration (i.e., short versus long) is constant within a block of trials but changes from block to block, the typical finding is a lengthening of RT in the blocks with long foreperiods, i.e., the fixed foreperiod effect. In contrast, if short and long foreperiods are randomly intermixed across trials within the same block, RT gets faster as the foreperiod duration increases, i.e., the variable foreperiod effect (hereafter called the foreperiod effect).

The discrepant findings between fixed and variable foreperiod designs are explained by two critical factors, *time estimation* and *conditional probability* of target occurrence, respectively. In the fixed foreperiod paradigm, participants may use the warning signal as a temporal reference to better tune their response to the onset of the target (Niemi & Näätänen, 1981; Klemmer, 1956; 1957). Considering that uncertainty in time estimation increases as a function of the time interval being estimated (Gibbon, 1977), it naturally follows that RT will also increase with longer durations. In other words, it is harder to estimate the onset of the target in constant (more uncertain) long-foreperiod blocks relative to constant (less uncertain) short-foreperiod blocks.

This situation dramatically changes when short and long foreperiods vary randomly from trial to trial. In this case, provided that each foreperiod has equal a priori probability to be presented in a trial, the conditional probability of target onset will grow with the passage of time, so that participants may infer that the target has to appear at the longest foreperiod given that it has not yet occurred at the shortest one (Elithorn & Lawrence, 1955). For example, as illustrated in Figure 1-A, if the target will occur after one of four possible foreperiods with equal probability, then the conditional probability that it occurs at one of these time intervals grows with the passage of time. Accordingly, the probability that the target will occur after the first foreperiod is 1 in 4 (i.e., 0.25). If the target does not occur after the first foreperiod, then the conditional probability of appearance will be 1 in 3 (i.e., 0.33). If it does not occur either after the second foreperiod, then there will be 0.50 probabilities that it will occur at the next foreperiod. Finally, if it has not yet occurred after the third foreperiod, then participants infer that it has to occur with full probability (i.e., p = 1) at the last time interval. It follows that participants' RT will decrease as a function of the increase of conditional probabilities over time (Figure 1-B). From this "strategic" point of view, the time course of temporal preparation would be modulated by participants' expectancies as to when the target stimulus will occur. The higher the temporal expectation, the faster the response speed.

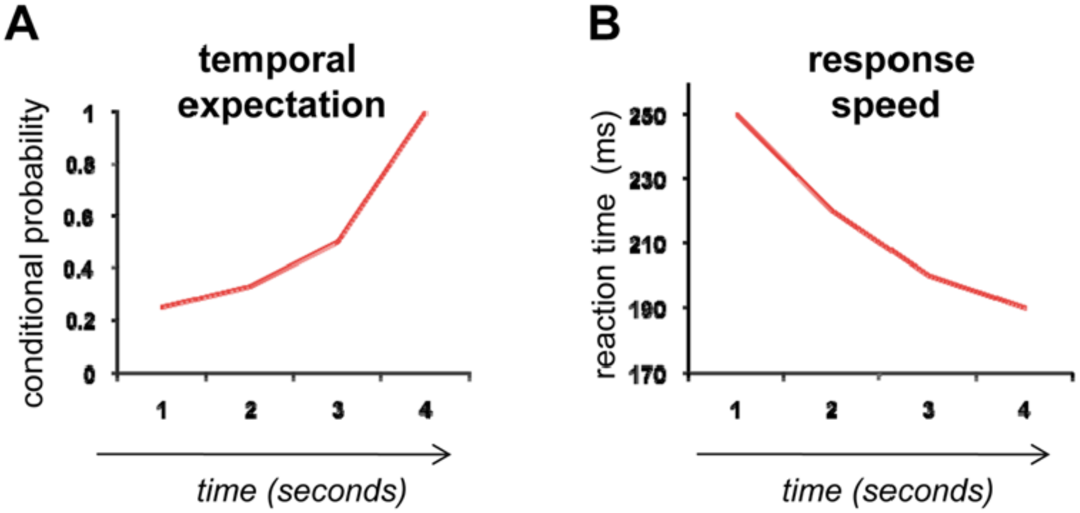

Figure 1. (A) Increasing conditional probabilities over time. (B) Participants' responses get faster as the foreperiod duration increases paralleling increasing conditional probabilities over time (i.e., the foreperiod effect). Reproduced from Coull (2009).

The strategic account of the foreperiod effect has been corroborated by early studies manipulating the conditional probability of target onset. The working hypothesis behind this research was as follows: if the foreperiod effect would depend on participants' temporal expectancy, then any change in the conditional probability of target occurrence should be reflected in the magnitude of the foreperiod effect. In line with this prediction, it has been shown that if the conditional probability of target onset was kept constant during the foreperiod (e.g., by using a "non-ageing" distribution that increased the a priori probability of the shortest foreperiods), a flat foreperiod effect was observed (Trillenberg, Verleger, Wascher, Wauschkuhn, & Wessel, 2000). In other words, a high probability of short foreperiods induced an early expectancy, so that the peak of preparation was already synchronized to the short time interval (Zahn & Rosenthal, 1966). In a similar way, if the frequency of the longest foreperiods was increased ("accelerating-ageing" distribution) a steeper foreperiod effect was obtained, as if a late expectancy biased preparation to the long time interval (Baumeister & Joubert, 1969; Zahn & Rosenthal, 1966).

Complementing the above studies, other evidence has shown that inducing uncertainty about the onset of the target by including a proportion of trials in which the target is not presented (i.e., catch trials) also influenced the foreperiod effect (Correa, Lupiáñez, & Tudela, 2006; Drazin, 1961). The typical result of using catch trials is a lengthening of RT, especially at long foreperiods (Drazin, 1961; Näätänen, 1972). According to Näätänen (1972), this RT increment would stem from a "dispreparation" effect caused by the lower a priori probability of target occurrence induced by catch trials. That is, as time goes by without target presentation, participants might reduce their expectancies so that they will be slower if the target surprisingly occurs at the long foreperiod.

Brain correlates of the strategic time-monitoring process have been related to prefrontal structures. The right dorsolateral prefrontal cortex (rDLPFC) has been particularly implicated in the foreperiod effect in studies using functional magnetic resonance imaging (Vallesi, McIntosh, Shallice, & Stuss, 2009), neuropsychological patients (Stuss, Alexander et al., 2005; Vallesi, Mussoni et al., 2007) and transcranical magnetic stimulation (Vallesi, Shallice, & Walsh, 2007). Other neuropsychological findings, however, have found deficiencies in the monitoring process in patients with either right or left frontal lesions (Triviño, Arnedo, Lupiáñez, Chirivella, & Correa, 2011; Triviño, Correa, Arnedo, & Lupiañez, 2010). Together, these results show that the prefrontal cortex plays a critical role in the on-line monitoring of temporal expectancies, which are built up on the basis of increasing conditional probabilities over time.

To sum up, the studies reviewed so far on the foreperiod effect suggest that our cognitive system is able to exploit the temporal information provided by the task context in order to optimize performance. In this framework, the question naturally arises as to whether temporal preparation can be placed under flexible control. Such a question provided a strong impetus in the research field of temporal preparation. The focus of interest was shifted from searching for the optimal foreperiod duration that allows maximal readiness after the presentation of the warning signal (e.g., Woodrow, 1914; Beterlson, 1967), to exploring how flexible our cognitive system would be to dynamically deploy attention in time on the basis of valid temporal predictions. In the following paragraph, we will make clear that this latter question had indeed a positive answer.

Temporal orienting: a step further

Coull and Nobre (1998; see Correa, 2010; Nobre, 2001, for reviews; see also Kingstone, 1992) used a temporal variant of Posner’s spatial orienting task (Posner, Snyder, & Davidson, 1980) to explore whether attention can be voluntarily deployed within the temporal domain. In a typical temporal orienting task, the warning signal acts as an explicit cue that predicts with high probability (e.g., 75%) the specific foreperiod interval (i.e., early versus late) at which the target stimulus is going to occur (Figure 2-A). Temporal orienting − or so-called validity − effects are typically revealed by faster and more accurate responses to targets appearing at early validly-cued time intervals as compared to earlier than expected late targets. At the long time interval, temporal orienting effects are usually smaller or even absent (Figure 2-B). The attenuation of temporal orienting effects at long intervals has been traditionally explained by a “reorienting of attention” process (Correa, Lupiáñez, Milliken, & Tudela, 2004; Coull & Nobre, 1998; Karlin, 1959). When the target does not appear shortly as predicted by the early cue, participants’ expectancy would be updated and their attention would be re-oriented to the longest interval accordingly. This means that when the cue is “early” but the target appears “late”, the conditional probability monitoring function will come into play thus counteracting the RT increase produced at the long interval by invalid temporal expectancies.

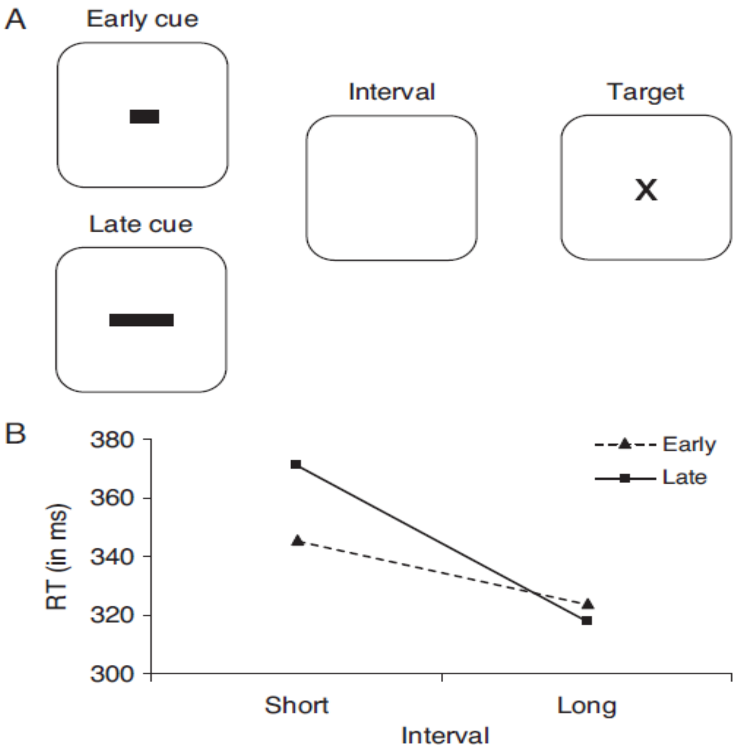

Figure 2. (A) An example of a typical orienting procedure which consists of a predictive temporal cue (early versus late), an interval (short versus long) and a target to which participants have to respond. (B) Validity effects usually observed in temporal orienting experiments. Reaction time at the short interval is faster for early cues as compared to late cues. At the long interval reaction time is generally similar for both early and late cues. Reproduced from Correa (2010).

To date, several studies have demonstrated the benefits of temporal orienting upon behavioural performance across a variety of task demands (e.g., Correa, Lupiañez, & Tudela, 2005, 2006; Griffin, Miniussi, & Nobre, 2002; Naccache, Blandin, & Dehaene, 2002). In their pioneering work, Coull and Nobre (1998; see also Davranche, Nazarian, Vidal, & Coull, 2011) used brain imaging techniques to investigate the neuroanatomical correlates of the behavioural advantages conferred by temporal orienting. They found that temporal orienting of attention was preferentially associated with left inferior parietal activity. As left parietal areas have been also involved in motor preparation tasks (e.g., Rushworth, Ellison, & Walsh, 2001), the authors concluded that temporal orienting of attention optimized performance by facilitating motor responses rather than by enhancing perceptual processing. Since then, a large body of research has challenged this point of view by providing evidence of enhanced performance in difficult perceptual discrimination tasks requiring, for example, to identify an expected validly-cued target embedded in a rapid serial visual presentation of distractors (Correa, Lupiañez, & Tudela, 2005; see also Correa, Sanabria, Spence, Tudela, & Lupiañez, 2006; Rolke & Hofmann, 2007). The finding of perceptual benefit by temporal orienting, however, does not weaken the contribution of valid temporal predictions to motor preparation. Event-related potential (ERP) studies show that temporal orienting enhances performance through facilitation of both perceptual and motor processes according to the specific task demands.

ERPs are scalp voltage fluctuations, time-locked to an event, which "reflect activity originating within the brain" (Coles & Rugg, 1995). An ERP waveform consists of a series of positive and negative deflections, which provide information about the neural stages involved in stimulus processing. That is, deflections that occur earlier would be related to perceptual processing (e.g., the P1 and N1 in posterior sites are linked to visual processing). By contrast, deflections that occur later (e.g., the N2 and P3) would reflect activity linked to decision or response processes. Given their high temporal resolution, ERPs offer an excellent tool for tracking the time course of ongoing cognitive processes.

In the first ERP study on temporal orienting (Miniussi, Wilding, Coull, & Nobre, 1999) a symbolic central cue (i.e., a cross symbol) predicted with a probability of 0.80 when the onset of the target (i.e., brightening of a central circle) would occur. ERPs evoked by valid versus invalid targets were compared at the short interval. The most important result was the modulation of the P3 latency by temporal orienting, such that it peaked earlier for valid relative to invalid targets. In addition, invalid targets elicited a larger N2. Miniussi and collaborators (1999) interpreted such findings as evidence for a late motor locus of temporal orienting effects. The sensitivity of the N2 and P3 potentials to temporal orienting was further corroborated by the same group in a follow-up study (Griffin, Miniussi, & Nobre, 2002). However, Griffin et al. (2002; Experiment 1) also reported a significant modulation of the early N1, which was increased in the attended condition as compared to the unattended condition. The main difference between the two studies was that in Miniussi et al. (1999) all the stimuli were presented foveally, thus reducing the need to further optimize visual processing to perform the simple-RT task. By contrast, in Griffin et al.'s (2002; Experiment 1) study, targets were presented peripherally and the task required a finer perceptual processing (i.e., the target was a pattern of concentric squares with one of its inner squares missing).

Taken together, Minussi et al.'s (1999) and Griffin et al.'s (2002) studies suggest that the modulation of temporal orienting at early stages of processing is contingent on the perceptual demands of the task at hand. Correa and collaborators (Correa, Lupiañez, Madrid, & Tudela, 2006) extended these earlier findings reporting a significant modulation of the P1 amplitude by valid targets as compared to invalid targets when a perceptually demanding (i.e., letter discrimination) task was used. Regarding the functional meaning of the N2 and P3 potentials in temporal orienting, it has been suggested that the N2 attenuation by valid targets as compared to invalid targets would be linked to a response inhibition process involved in avoiding a premature response at inappropriate times. The reduced P3 latency would instead reflect the synchronization and preparation of fast responses to the upcoming event.

To further investigate the dynamics of temporal orienting during target anticipation, ERPs studies have also focused on the modulation of the contingent negative variation (CNV). The CNV is a slow negative deflection occurring during the foreperiod between a warning signal and a stimulus that requires a response, which is usually maximal over fronto-central regions (Walter, Cooper, Aldridge, McCallum, & Winter, 1964). This potential tends to be more negative at around the time of the second stimulus. The CNV was first described as an "expectancy" wave since in the original experiments (Walter et al., 1964) it did not occur when the two stimuli (i.e., a click and a flickering light to which participants were to respond) were presented alone. However, the CNV has been also related to motor preparation (Brunia & van Boxtel, 2001) and timing processes (Macar & Vidal, 2003). Temporal orienting studies have shown increased (i.e., more negative) CNV at the moment of expected early target onset after an early cue predicting a short interval rather than after a late cue predicting a long interval (Los & Heslenfeld, 2005; Correa et al., 2006; Griffin et al., 2002; Miniussi, Wilding, Coull, & Nobre, 1999). These results suggest that temporal expectancies triggered by symbolic cues optimize participants' performance by encouraging them to prepare an appropriate response at the expected moment in time.

A more recent ERP research by Correa and Nobre (2008) has explored the neural modulation of target processing as a function of both temporal orienting and foreperiod effects. As described above, the finding of attenuated validity effects at the long interval may be accounted for by the involvement of time-monitoring processes, which would reduce the behavioural cost of an invalid prediction. Based on this evidence, the authors explored how the behavioural interaction between the effects of temporal orienting and foreperiod duration would be expressed in ERP measures. They used a rhythm motion task (see also Doherty, Rao, Mesulam, & Nobre, 2005), in which a ball moved across the screen in a regular or irregular pace before going occluded under a peripherally located band, to manipulate (1) whether the target reappeared from the occluding band at the expected (valid trials) versus unexpected (invalid trials) moment following the rhythm, and (2) the duration of the occlusion interval (short, medium or long). The results showed faster RT for valid trials as compared to invalid trials (temporal orienting effects), as well as faster RT after long occlusion intervals (foreperiod effects). The behavioural effects produced by these two sources of temporal expectancies interacted significantly to improve performance, as temporal orienting effects were significant only after short occlusion intervals while foreperiod effects were reported only on invalid trials. In the same way, ERP analysis showed a neural overlap between temporal orienting and foreperiod effects on late perceptual and response selection potentials. Temporal orienting attenuated the N2 amplitude and decreased the P3 latency only after short occlusion intervals, whereas foreperiod effects attenuated the N1 and N2 amplitudes and decreased the P3 latency only on invalid trials.

Correa and Nobre's study (2008) hence suggests that foreperiod and temporal orienting effects may engage a common strategic mechanism. Support for this idea comes from a functional imaging study (Coull, Frith, Büchel, & Nobre, 2000) showing that targets occurring at the late interval after an invalid early cue (i.e., "delayed trials") activate a cluster of right frontal areas that have also been involved in the foreperiod effect (Vallesi et al., 2009). Based on these studies, Coull (2010) has proposed that the right prefrontal cortex may be a critical region for the on-line monitoring and updating of temporal expectancies as a function of changing conditional probabilities over time. A recent neuropsychological study has further corroborated this idea by showing both foreperiod and temporal orienting effects to be impaired in patients with right frontal lesions (Triviño, Correa, Arnedo, & Lupiáñez, 2010).

As interim conclusion, the studies reviewed so far on foreperiod and temporal orienting effects suggest that temporal preparation may be placed under flexible voluntary control on the basis of participants' expectancies. However, there is evidence that temporal preparation may be also influenced automatically by the preparatory state developed on the previous trial, a phenomenon known as sequential effects. Temporal sequential effects will be the focus of the next section.

Sequential effects in temporal preparation

Sequential effects are a robust phenomenon, firstly observed in the variable foreperiod paradigm (e.g., Drazin, 1961; Woodrow, 1914; see also Los & Van den Heuvel, 2001; Steinborn, Rolke, Bratzke, & Ulrich, 2008; Vallesi & Shallice, 2007). Sequential effects imply that participants' RT on current short trials is typically faster when the previous foreperiod was short rather than long. By contrast, on current long trials responses are fast for either a previous short or long foreperiod (Figure 3). On the basis of this RT pattern, sequential effects are usually referred to as "asymmetric".

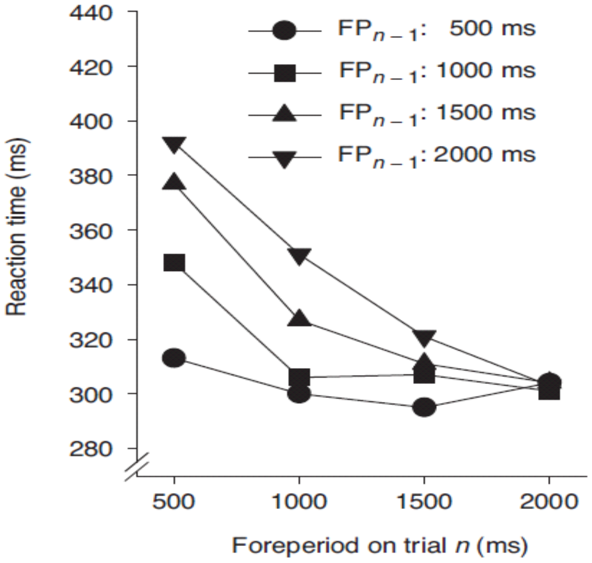

Figure 3. Sequential effects in a variable foreperiod paradigm. Reaction time at the current short foreperiod (FP $_n$*) is faster for previous shorter as compared to previous longer foreperiods (FP* $_{n-1}$*). At the current long foreperiod, reaction time is equally fast for previous short and long foreperiods. Reproduced from Los (2010).*

Since the first reports, there has been a long-standing debate in the literature about the cognitive processes underlying such effects. One of the earliest points of view explained sequential effects in terms of strategic or intentionally driven processes (e.g., Alegria, 1975; Niemi & Näätänen, 1981; Requin, Brener, & Ring, 1991). According to this strategic account, at the start of each trial participants would expect a repetition of the previous foreperiod rather than an alternation. Hence, if the onset of the target matches this expectation, as in short-short and long-long foreperiod sequences, participants' RT is speeded up. By contrast, if the target occurs earlier than expected, namely, at the short foreperiod after a previous long foreperiod, participants would be caught in a state of low preparation and RT is lengthened. This RT cost would not occur when a short foreperiod precedes a current long foreperiod, since participants would realize their incorrect expectation in due time and voluntarily re-prepare to a long foreperiod. Re-preparation strategy can thus account for the asymmetry of sequential effects.

The strategic account of sequential effects, however, was challenged by studies showing that, in sequences with two equiprobable alternatives, participants are more prone to expect an alternation rather than a repetition of the alternatives (e.g., the gambler's fallacy; Soetens, Boer, & Hueting, 1985 cited in Vallesi, Mussoni et al. 2007). More recently, the strategic view has also been weakened by Los and coworkers who proposed an alternative account referred to as the "trace-conditioning" view of temporal preparation (Los, 1996; Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001).

The-trace conditioning view

The starting point of the trace-conditioning view is the assumption that temporal preparation is not a strategic, volitionally driven process, but, rather, a conditioned response that is automatically elicited by the warning signal. In particular, it is assumed that the variable foreperiod design would be quite similar to that used to study trace conditioning with animal models (e.g., Gallistel & Gibbon, 2000; Machado, 1997). Accordingly, the development of temporal preparation during the foreperiod would rely on the same underlying conditioning principles. In classical conditioning experiments, an initial association is established between an unconditioned stimulus (US) and an unconditioned response (UR) ─ for instance, the association between food and the production of saliva in the classical Pavlov's (1927) study. During the acquisition phase, a conditioned stimulus (CS), for example a tone, precedes the presentation of the US. It follows that after some paired presentations the CS becomes associated with the US, as reflected by the occurrence of a conditioned response (CR) even when the CS is presented alone. The key feature of the trace conditioning paradigm is that the CS and the US do not overlap. They are instead separated by a blank interstimulus interval, or trace, during which no stimuli are presented. In this sense the association between CS and US is based on a memory trace that has to be maintained after the CS presentation in order to associate it with the US.

In analogy to trace-conditioning in animal models, Los et al. (Los, 1996; Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001) suggest that the target stimulus would be similar to an US which entails a tendency to respond as fast as possible. The warning signal would be a CS, which, after some practice (acquisition phase), results in the development of a CR (Los et al., 2001, p.125). In this design, the foreperiod would constitute the trace, namely the blank CS-US interval. The core assumption of the conditioning view is that the warning signal, in the quality of a CS, elicits a state of conditioning that fluctuates over time as the foreperiod develops. Each critical moment (i.e., possible moment of target presentation) is associated with a conditioned strength that increases or decays during the foreperiod on a trial-by-trial basis obeying to three learning rules (Machado, 1997). This set of rules involves that the strength of the conditioned response associated with a critical moment is: 1) *reinforced* if the critical moment actually occurs and is responded to; 2) *extinguished* if the critical moment is bypassed during the foreperiod; 3) *unchanged* if the critical moment occurs later than the actual target presentation. For example, in a design manipulating four foreperiod durations, at the start of a given trial each of these durations would have equal conditioned strength. If the target then occurs at the third duration, the conditioned strengths associated with the first two durations would decrease as they were bypassed during the foreperiod (extinction rule). The conditioned strength associated with the third duration, which coincided with the target appearance, would instead be reinforced. Finally, the conditioned strength associated with the last foreperiod duration would persist, that is, it remained unchanged since it was not bypassed during the foreperiod. On the next trial, if the target occurs at each one of the first two foreperiod durations, participants' responses would be slow since the conditioned strengths associated with them had been actually extinguished on the previous trial. By contrast, if the target occurs either at the third or at the last duration, RT would be equally fast in force of the reinforcement and persistence learning rules operating on the previous trial, respectively (cf. Los, 2010). It follows that only conditioned strengths associated with the short foreperiod are subject to extinction. In contrast, conditioned strengths associated with the long foreperiod are subject to either reinforcement or no-reinforcement (i.e., they persist) but not to extinction. In a recent extension of the trace-conditioning model, Los (2010) proposed that extinction would be "implemented by an inhibitory process that serves to prevent participants from premature responding during foreperiod" (p. 296). The differential involvement of extinction in short versus long foreperiods would account for the asymmetry of sequential effects. Moreover, the trace-conditioning model explains the foreperiod effect by considering it as a direct consequence of sequential effects, since RT on trial *n* is a by-product of the conditioning mechanisms operating on trial *n-1*.

To sum up, Los' model (Los, 1996; Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001) considers both foreperiod and sequential effects as the outcome of a single process, which is regulated automatically by trace conditioning. However, there is evidence showing that these two temporal effects can be dissociated at both functional and anatomical levels (e.g., Triviño et al., 2011; Triviño et al., 2010; Vallesi, Mussoni et al., 2007; Vallesi, Shallice, & Walsh, 2007). Thus, to the extent that the foreperiod effect can be dissociated from sequential effects, a single-process cannot longer hold. This conclusion mainly relies on the work done by Vallesi and collaborators (Vallesi, 2010; Vallesi & Shallice, 2007; Vallesi, Shallice, & Walsh, 2007) who proposed a hybrid "dual-process" model, combining automatic and controlled processing, to account for temporal preparation effects.

The-dual process view

The key feature of the dual-process model is the idea that temporal preparation would be the result of two influences. The first is based on the conditional probability monitoring of target onset across the foreperiod. As described earlier, this influence is assumed to be strategic since it would rely on the tracking of elapsed time over the course of a trial (i.e., the target will certainly appear at the longest foreperiod if it has not yet occurred). The second influence would be related to motor automatic arousal modulation (or readiness to respond) resulting from the previous trial. Assuming that maintaining a heightened preparatory state is effortful and energy consuming (e.g., Alegria, 1975; Gottsdanker, 1975; Naatanen, 1972), a previous long foreperiod would decrease participants' arousal on the current trial thus lengthening RT. By contrast, a previous short foreperiod would increase the general participants' level of arousal thus speeding up RT. This automatic arousal effect from the previous trial would operate regardless of the duration of the current foreperiod. A key aspect of the model is that, on the current long foreperiod, the low arousal level from a previous long trial would be compensated by the controlled influence of the monitoring process. That is, as time goes by without target occurrence, participants' preparatory state would grow as a function of the passage of time itself, thus contrasting the negative effect on RT of a previous − less arousing − long foreperiod. Accordingly, the dual-process model would explain the benefit observed in short-short sequences as compared to long-short sequences through automatic arousal modulation from a previous short foreperiod, whereas the asymmetry of sequential effects through the time-monitoring function operating at the current long foreperiod.

The dual-process model challenged the trace-conditioning view in a series of studies providing evidence for dissociable processes contributing to foreperiod and sequential effects. Building on the assumption that the time-monitoring function, which is thought to underlie the foreperiod effect, depends on intact rDLPFC (e.g. Stuss et al., 2005; Vallesi, Shallice and Walsh, 2007) applied repetitive transcranial magnetic stimulation (TMS) to this brain area in the context of a variable foreperiod design. The rationale for this study was that if a shared mechanism underlies both foreperiod and sequential effects, as proposed by the trace-conditioning view (Los, 2010), then stimulation on the rDLPFC should modulate the two effects to the same degree. If instead they arise from dissociable mechanisms, a clear dissociation between the two should be observed. The results confirmed Vallesi et al.'s (2007) predictions by showing a selective reduction of the foreperiod effect after stimulation over the rDLPFC (with respect to a pre-TMS baseline and to stimulation over the left DLPFC and another control site in the right angular gyrus). By contrast, sequential effects were not influenced by TMS on the rDLPFC, which suggested the involvement of a different neural system to that implicated in the foreperiod effect. Moreover, this study showed that when the time-monitoring process was not working properly after stimulation on the rDLPFC, a symmetric pattern of sequential effects was displayed thereby supporting the influence of controlled factors in determining the asymmetry of these effects.

In addition to the TMS findings, Vallesi & Shallice (2007) also showed sequential effects to follow a different developmental trajectory as compared to the foreperiod effect. That is, whereas the foreperiod effect gradually develops as a function of age from 4-5 years to older ages, sequential effects were already present even in a young population of 4 years old infants. This result was taken as further evidence that the foreperiod effect would depend on the functioning of the prefrontal cortex, which is known to myelinate slowly as compared to other parts of the brain (Huttenlocher, 1979, 1990). Conversely, sequential effects would depend on the involvement of more primitive brain structures. Specifically, Vallesi et al. (2007) proposed the left premotor cortex as a plausible neural candidate for sequential effects. In their tumor patient study, the authors found no benefit for a short-short foreperiod sequence after left premotor tumor excision. This result is agreement with the idea of a premotor locus for sequential effects (i.e., motor arousal modulation). However, the involvement of this brain area in sequential effects deserves further investigation since the interaction with the other patient groups was missing in the overall analysis.

Together, the studies by Vallesi et al. (see Vallesi, 2010, for a recent overview) suggest that foreperiod and sequential effects may arise from dissociable mechanisms. At this point, one might wonder whether the same conclusion could also be drawn for temporal orienting and sequential effects. In other words, would sequential effects still occur when participants receive valid information about the most likely moment of target onset? If so, do temporal orienting and sequential effects arise from single or dissociable processes? To date, we do not have a conclusive answer to these questions. The principal problem is that early temporal orienting research did not investigate the contribution of sequential effects. The next section gives a brief overview on most recent work on temporal orienting and sequential effects.

Temporal orienting versus sequential effects

Los and Van den Heuvel (2001) firstly furthered the idea that temporal orienting and sequential effects may contribute independently to the development of temporal preparation. The authors presented participants with a temporal orienting paradigm in which a cue provided valid, invalid or neutral information about the duration of the forthcoming foreperiod. The results of this study showed that sequential effects were virtually eliminated in the valid condition, demonstrating that participants effectively used the information provided by the cue in order to optimize performance. By contrast, sequential effects were stronger in invalid (and neutral) conditions, namely, when the focus of attentional control was directed away by an invalid (and neutral) prediction. From these findings, the authors concluded that “the provision of a valid cue encourages participants to make an intentional contribution to a state of nonspecific preparation that is normally regulated by conditioning processes alone” (p.382). In other words, according to Los and Van den Heuvel (2001), the fact that sequential effects may be reduced by temporal orienting does not falsify their automatic nature. It just provides evidence in favor of the idea that temporal orienting may influence the preparatory state only if participants are explicitly encouraged to rely on a valid prediction. Otherwise, in the absence of explicit cues (i.e., invalid and neutral conditions) temporal preparation would be automatically driven by automatic trace-conditioning rules.

Within this context, it could also be argued that since temporal orienting procedures involve sequential presentation of different foreperiod lengths, temporal orienting effects might be influenced by sequential effects. This possibility would be especially likely in a blocked-manipulation of temporal cues including a high frequency of short (i.e., early block) intertrial transitions. According to Los’ trace-conditioning rules (Los, 1996; Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001), the conditioned strength associated with the early moment would receive more reinforcement and less extinction since they are less often bypassed during the foreperiod, thus affecting the final shape of temporal orienting effects. This hypothesis, however, was rejected by Correa and coworkers (Correa et al., 2004; Correa et al., 2006) who reported significant temporal orienting effects that were independent from sequential effects in the context of a blocked-manipulation of temporal cues. These results thus show that temporal orienting can be elicited independently from sequential effects.

The idea that temporal orienting and sequential effects both can contribute to the development of temporal preparation has received increasing support from electrophysiological and neuropsychological studies. Los and Heslenfeld (2005) used the CNV to investigate the consequences of temporal orienting and sequential effects on participants' state of preparation using a temporal orienting design (valid versus neutral cues). They reported a more negative CNV when the previous foreperiod was short as compared to long in both valid and neutral conditions. Crucially, this sequential effect was not reduced at the short foreperiod even when a valid cue specified a long foreperiod, thus supporting the idea that sequential effects can contribute independently from explicit predictions to temporal preparation. Unfortunately, however, since Los and Heslenfeld' s (2005) study did not take target processing into account, a direct comparison between the modulation of temporal orienting and sequential effects on target processing was not possible. This point is of particular importance for the current thesis since, to date, very little is known about how sequential effects can influence information processing (we will come back to this issue in the General Discussion section).

Recent neuropsychological evidence has further emphasized the dissociation between temporal orienting and sequential effects. Triviño, Correa, Arnedo and Lupiañez (2010) administered a temporal orienting task to a group of patients with prefrontal lesions, a group of control participants and a group of patients with a basal ganglia lesion. They found that patients with right prefrontal lesion showed a severe deficit in temporal orienting. By contrast, sequential effects were not diminished in any of the two groups of patients as compared to control participants. These results suggest that while temporal orienting of attention depends on the intact functioning of the right prefrontal cortex, sequential effects do not, a result that the authors interpreted as evidence for their automatic nature.

To sum up, the studies reviewed in this last section about temporal orienting and sequential effects suggest that dissociable processes might be responsible for the two effects. In particular, Triviño et al.'s (2010) findings are quite remarkable in revealing distinct brain correlates of temporal orienting with respect to sequential effects. However, concluding that temporal orienting would rely on controlled processing, while sequential effects on automatic processing, solely on the basis of neuropsychological evidence could be questioned to the extent that this neural criterion does not provide direct evidence on the cognitive processes involved in the two temporal effects. Building up on this rationale, in the present thesis we adopted a dual-task approach to test directly the automaticity of both temporal orienting and sequential effects in the same experimental design.

The next chapter describes our experimental approach and the main aims of the present thesis.

Chapter III: Aims of the thesis

The studies reviewed in the Introduction suggest that temporal preparation is not a unitary phenomenon. The present thesis aimed to investigate the specific mechanisms by which temporal preparation can be accomplished. In particular, we had two goals in mind: a) to disentangle the contribution of controlled and automatic processes in temporal preparation; and b) to explore the electrophysiological correlates of different temporal preparation effects. The three experimental series of this dissertation tried to pursue these main aims. In the next paragraphs, we describe in details the specific objectives of each series and the experimental approach that we have followed to address our opening question as to whether temporal preparation relies on controlled or automatic processes.

Series I. Dissociating controlled from automatic processing in temporal preparation

The experimental section begins with a behavioural study that includes three experiments employing a dual-task paradigm. The starting point for this work builds up on previous research providing behavioural (Correa, Lupiáñez, & Tudela, 2006; Correa, Lupiáñez, Milliken, & Tudela, 2004; Los and Van den Heuvel, 2001), electrophysiological (Los & Heslenfeld, 2005) and neuropsychological (Triviño, Correa, Arnedo, & Lupiañez, 2010) dissociations between temporal orienting of attention and sequential effects. All of these studies point to the idea that distinct underlying cognitive processes might be responsible for the two temporal effects. However, a direct test of the controlled versus the automatic nature of temporal orienting and sequential effects was still missing in the literature. In the first experimental series of the thesis, we used a dual-task methodology to tackle this question.

Dual-task paradigms, in which participants are confronted with two simultaneously tasks (called the primary and the secondary task), have commonly been used in Cognitive Psychology for inferring the nature of targeted cognitive processes (see Pashler, 1994, for a review). According to Posner and Snyder (1975), the primary task would involve controlled processing when the addition of a concurrent task would impair behaviour by decreasing participants' performance, whereas the primary task would involve automatic processing when performance would not be diminished by the secondary task (see also Logan, 1978, 1979). Thus, the main goal of Series I was to test the automatic versus the controlled nature of temporal orienting and sequential effects by probing whether these two effects would survive or suffer interference from a concurrent secondary task.

The primary task was a temporal orienting task similar to that described earlier in the Introduction (e.g., Correa, 2010; Nobre, 2001). In addition, a concurrent working memory paradigm was included as secondary task, which required participants to mentally update cue colour information on a trial-by-trial basis. It is, in fact, well-established that working memory and time estimation of intervals in the range of seconds tap into the same cognitive resources (e.g., Brown, 2006; Fortin & Breton, 1995) and prefrontal structures (see Lewis & Miall, 2006, for a review) that are also related to temporal orienting effects (Coull & Nobre, 1998; Triviño et al., 2011; Triviño et al., 2010). Accordingly, we had the following main hypotheses:

1) If temporal orienting involves controlled processing, as suggested by previous research (e.g., Correa et al., 2006; Coull & Nobre, 1998; Triviño et al., 2010), then it should be attenuated by the addition of a concurrent working memory task.

2) If sequential effects involve automatic processing (e.g., Los & Van den Heuvel, 2001; Vallesi & Shallice, 2007), then they should not be reduced by the addition of a concurrent working memory task.

We manipulated the competition for attentional resources between temporal orienting and working memory tasks across three experiments, such that maximal competition occurred when the same stimulus was used to generate temporal expectancy and working memory updating (Experiment 2) rather than when the temporal cue and the working memory cue were presented separately (Experiments 1 and 3). The results of Series I showed that sequential effects resisted to dual-task interference, while temporal orienting was reduced as a function of the competition for executive resources required by both temporal preparation and working memory tasks. We interpret such pattern of findings as evidence that there is not a clear dichotomy but a gradation between automaticity and control in temporal preparation. In Series II, we were interested in delve further into the dissociation between controlled and automatic temporal preparation by means of ERP measures.

Series II. Temporal orienting of attention is interfered by concurrent working memory updating

The disruption of temporal orienting effects observed in Series I showed that when executive resources were depleted by a demanding secondary task, there was not behavioural benefit by a valid temporal prediction. This result was suggestive of the involvement of controlled processing in the ability to orient attention in time. The second series of the thesis includes an electrophysiological study that capitalizes on the high temporal resolution of ERPs to identify at which stages of the stimulus processing the interference between temporal orienting and working memory tasks emerges.

The target-locked N2 and P3 potentials were employed as electrophysiological markers of temporal orienting effects (e.g., Nobre, 2001). In addition, we focused on the analysis of the CNV, as an index of preparatory activity preceding the onset of the target, to compare the time course of temporal preparation between single-task and dual-task conditions. We predicted temporal orienting to modulate the cue-locked CNV as well as the target-locked N2 and P3 potentials only in the single-task but not in the dual-task condition.

As second aim, Series II explored how the behavioural dissociation between temporal orienting and sequential effects would be expressed at the electrophysiological level. This analysis was important to provide stronger support to the dissociation between temporal orienting and sequential effects on the basis of modulation at different target processing stages. Moreover, building on the results of Series I revealing no reduction of sequential effects by dual-task interference, we expected the ERP pattern associated to sequential effects in the single-task condition to be also unaffected in the dual-task condition.

Concerning the main goal of this ERP study, the results corroborated the controlled nature of temporal orienting revealing a selective interference between dual-task demands and specific neural signatures of temporal orienting of attention (i.e., N2 amplitude and P3 latency). Regarding sequential effects, we found that they modulated the cue-locked CNV and the target-locked N2 and P3 potentials in a similar way as temporal orienting did under both the single-task and the dual-task condition. The main difference between the two temporal effects was reported at the early latencies of the P1 and N1 visual potentials, which were affected by sequential effects only. As further evidence for the specific modulation of early processing by sequential effects, the P1 potential survived to dual-task interference.

The neural overlap observed at late stages of target processing between temporal orienting and sequential effects raised the question as to whether the temporal orienting paradigm used in Series II would be the optimal procedure to study the "pure" contribution of automatic processing in sequential effects, without the simultaneous influence of temporal expectancies induced by the probabilistic cueing. In this context of attentional control, it has been shown that a valid temporal cue reduced the magnitude of sequential effects, which were indeed larger on invalid cue conditions (Los & Van den Heuvel, 2001). In order to better isolate the electrophysiological correlates of sequential effects, we designed another ERP study. The key manipulation here was the substitution of a highly predictive temporal cue for a neutral warning signal that was aimed to prevent the influence of controlled factors driven by valid temporal predictions.

Series III. Electrophysiological correlates of temporal sequential effects

The last series of the present thesis tackles the question of how sequential effects modulate target processing when an explicit temporal expectancy is prevented by introducing a neutral warning signal. If the design of Series III would still yield sequential effects on early visual potentials (i.e., P1), as reported in the previous series, it would confirm the novel finding that automatic temporal preparation driven by sequential effects may enhance perceptual processing.

Chapter IV: Dissociating controlled from automatic processing in temporal preparation

The content of this chapter has been published as Capizzi, M., Sanabria, D. & Correa, A. (2012). Dissociating controlled from automatic processing in temporal preparation. *Cognition, 123*, 293-302.

Abstract

The aim of the present study was to investigate the controlled versus the automatic nature of temporal preparation. If temporal preparation involves controlled rather than automatic processing, it should be reduced by the addition of a concurrent demanding task. This hypothesis was tested by comparing participants' performance in a temporal orienting task that measured two main effects of temporal preparation (temporal orienting and sequential effects) between a single-task and a dual-task condition. In the single-task condition, participants responded to a visual target presented after symbolic cues that were highly predictive of the moment of target onset. In the dual-task condition, the temporal preparation task was performed concurrently with a working memory task. The results showed that sequential effects survived to dual-task interference, while temporal orienting was reduced as a function of the competition for executive resources required by both working memory and temporal preparation tasks. These findings provide direct behavioural evidence that temporal orienting and sequential effects involve dissociable cognitive processes.

Introduction

The ability to anticipate and prepare an optimized response to forthcoming events, i.e. temporal preparation, is essential to many forms of cognitive and motor behaviour (Nobre, Correa, & Coull, 2007). Temporal preparation can be flexibly built up on the basis of different information, such as that provided by temporal predictions (temporal orienting effects) and duration of the preceding time interval (sequential effects). An ongoing debate in the literature is to what extent these temporal preparation effects are mediated by controlled or automatic processing. To address this issue, in the present study we used a dual-task paradigm in which a temporal preparation task had to be performed concurrently with a working memory (WM) task. Our aim was to test the nature of the processes involved in these two main temporal preparation effects by investigating whether they would survive or suffer interference from a concurrent secondary task.

One of the most used experimental procedures to measure temporal preparation is the temporal orienting task (Coull and Nobre, 1998; see Nobre, 2001, for a review). In this paradigm, which was modelled after Posner's spatial orienting task (Posner, Snyder, & Davidson, 1980), a symbolic cue predicts with high probability the specific time interval (i.e., early versus late) at which the target stimulus would occur. Temporal orienting effects are typically revealed by faster and/or more accurate responses to targets appearing at early validly cued temporal intervals as compared to earlier than expected targets. At the long time interval, temporal orienting effects are usually smaller or even absent. A widely accepted proposal put forward by some authors (Correa, Lupiáñez, Milliken, & Tudela, 2004; Coull & Nobre, 1998; Karlin, 1959) to explain the attenuation of temporal orienting effects at the long interval is based on the "reorienting of attention". According to it, if the target does not appear early as predicted, participants infer that it will appear later, which enables them to reorient their attention accordingly.

Another reliable finding in temporal preparation research concerns the influence of the previous time interval duration on performance in the current trial. Participants' RT is typically faster when a short interval is preceded by another short rather than long interval, i.e., *sequential effects* (Drazin, 1961; Los & Van den Heuvel, 2001; Steinborn, Rolke, Bratzke, & Ulrich, 2008; Vallesi & Shallice, 2007; Woodrow, 1914). Sequential effects are usually asymmetric since at the long time interval participants' RT is equally fast when the previous interval was either short or long.

It has been suggested that sequential effects are 'automatic', reflecting the involvement of processes exogenously triggered by stimulus sequence association from one trial to the next, rather than by internal volitional expectations (see Los' trace conditioning account for further details, Los, 1996; Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001). In support of the automaticity of sequential effects, behavioural and electrophysiological studies have found dissociations between temporal orienting and sequential effects (Correa et al., 2004; Correa, Lupiáñez, & Tudela, 2006; Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001). For example, Los and Van den Heuvel (2001) first demonstrated that sequential effects are stronger in the absence of temporal orienting effects, after invalid temporal cues, than in the presence of temporal orienting, after valid temporal cues. More recent neuropsychological research has shown that patients with prefrontal lesions exhibit intact sequential effects, despite reduced temporal orienting effects (Triviño et al., 2010). Triviño et al.'s study (2010) suggests that different temporal preparation processes might underlie the dissociation between temporal orienting and sequential effects. That is, temporal orienting effects would involve controlled processing as they would depend on the functioning of a typical structure of attentional control (i.e., the prefrontal cortex), while sequential effects would be the result of automatic processing as they would not require the involvement of the prefrontal cortex. However, this neural criterion could be questioned since it only supports the distinction between automatic and controlled temporal preparation processing rather indirectly. It remains to be determined the extent to which temporal preparation effects are accomplished by automatic or controlled processing. To our knowledge, no study has yet tested directly the automaticity of both temporal orienting and sequential effects in a single experimental design (but see Van Lambagen & Los, 2008, for a dual-task study on sequential effects). Therefore, our goal was to explore the nature of the processes involved in these two main temporal preparation effects by comparing how they would behave in a dual-task context.

In a typical dual-task experiment, two tasks (commonly called the primary and the secondary task) are performed simultaneously. Assuming that primary and secondary tasks compete for common limited resources, the addition of a secondary task should interfere with performance on the primary task (e.g., Logan, 1979). Thus, the key criterion in our study to dissociate controlled from automatic temporal preparation was that the primary task involves controlled processing when the addition of a concurrent task would impair behaviour by decreasing participants' performance, whereas the primary task involves automatic processing when performance would not be diminished by the secondary task (Logan, 1978, 1979; Posner & Snyder, 1975). In our dual-task study, the primary task was a simple-RT task that measured temporal preparation. Participants had to respond to a visual target that was preceded by a symbolic cue (a short versus a long line) and that appeared after one of two different time intervals in the seconds range (1 s versus 3 s). The secondary task demanded WM, i.e. under dual-task conditions participants performed a mental counting task in which they continuously updated information held in WM.

We decided to use a WM task as secondary task on the basis of the following evidence. First, previous dual-task studies have shown interference between WM and time estimation of intervals in the range of seconds, suggesting that these two tasks may draw on the same cognitive resources for executive control (e.g., Brown, 2006; Fortin & Breton, 1995). Second, both WM and timing tasks have been shown to engage prefrontal structures (see Lewis & Miall, 2006, for a review), which likewise relate to temporal orienting effects (Coull & Nobre, 1998; Triviño et al., 2010). According to the above findings, we reasoned that if temporal orienting effects rely on controlled processing, they should be reduced by the addition of a demanding secondary task. By contrast, if sequential effects are automatically elicited by stimulus sequence association, they should not be attenuated by the addition of a concurrent task.

Experiment 1

In Experiment 1, the primary task was a simple-RT task in which temporal expectancy was manipulated between blocks of trials to optimize the finding of attentional effects (Correa et al., 2006). The secondary task of the dual-task condition required concurrently updating the count of different colours that the temporal cues displayed on every trial and reporting the final count at the end of each block. Based on a previous study showing reduced temporal orienting effects after prefrontal damage (Triviño et al., 2010), we expected temporal orienting, but not sequential effects, to be attenuated by competing WM demands in the dual-task condition as compared to the single-task condition.

Method

Participants. Fifty-nine undergraduates from the University of Granada (forty-seven females, five left-handed, age range: 18-34 years old) took part in Experiment 1. Data from one participant were excluded from analysis due to missing observations in one experimental condition. All the participants in all the experiments reported in this article had normal or corrected-to-normal vision, none of them was colour-blind, and all received course credits for their participation. The study was conducted in accordance with the ethical standards of the1964 Declaration of Helsinki.

Apparatus and stimuli. The experiment was run on an Intel Core 2 Duo personal computer connected to a 17" LCD monitor. Stimulus presentation and data recording were controlled by E-prime software (Schneider, Eschman, & Zuccolotto, 2002). The viewing distance was approximately 57 cm. All stimuli were presented on a black background in the centre of the screen. The temporal cues consisted of a short line (3.4º x 1.3º visual angle) and a long line (7.5º x 1.3º) presented either in red, green or blue. The short line indicated that the target would probably appear early (after 1 s) and the long line indicated that the target would probably appear late (after 3 s). The target stimulus was a white dot (diameter: 1.5º).

Procedure and Task. Participants were tested in a silent and dimly illuminated room. Both written and verbal instructions were provided for the single-task and the dual-task condition. A trial of the single-task block began with the presentation of a blank screen for a random duration between 500 and 1000 ms (see Figure 4). The temporal cue, filled with one of three colours (red, green, or blue), was then displayed for 750 ms. Each colour was randomly generated at the beginning of each trial with the same probability of appearance. Participants were told that the colour of the temporal cue was task-irrelevant and should therefore ignore it. Following the cue, the screen remained blank for a variable delay of either 1 or 3 s, depending on the time interval for that trial.

After the time interval elapsed, the target stimulus was presented for 100 ms and then disappeared. Participants had to respond to the target onset as quickly as possible by pressing the spacebar with the index finger of their preferred hand. They were explicitly informed that the temporal cue would help them to predict the occurrence of the forthcoming target. A visual feedback message was displayed for 500 ms either in case a premature response was given before the onset of the target ("wait for the target") or if no response was made within 1100 ms after the offset of the target ("respond earlier"). Following the response to the target, or after 1100 ms in case of a missed response, the next trial began.

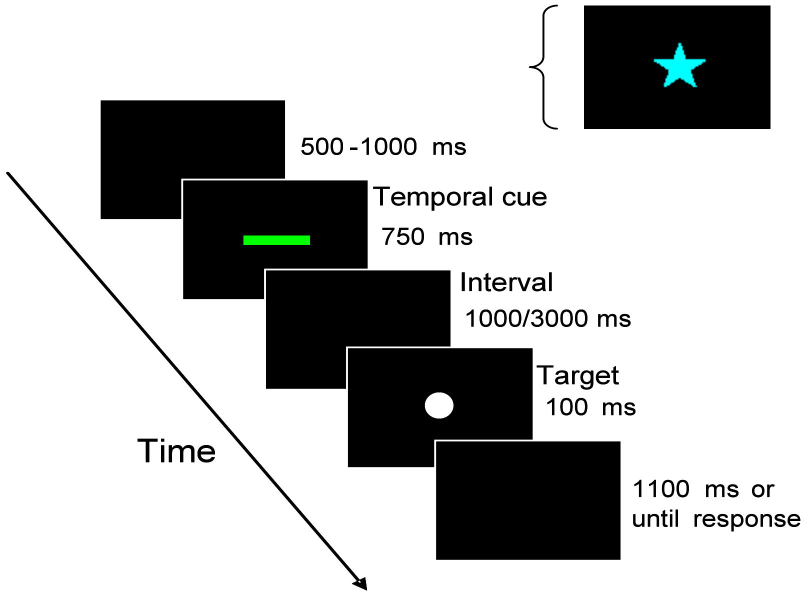

Figure 4. Schematic representation of events in a trial in Experiments 1 and 2. The only variation was that in Experiment 3 the temporal cue was presented in gray and the memory stimulus consisted of one of three coloured (red, green or blue) stars.

In the dual-task condition, the temporal preparation task remained the same as that described above. The only difference with respect to the single-task condition was the addition of the concurrent WM task. The WM task required participants to count and remember how many times each temporal cue colour appeared during a block of trials. At the end of the block, one of the three colours was randomly chosen (e.g., "*red*") and participants had to type how many times that colour had been presented. Each colour was equally probable to be selected for the memory test. This task encouraged participants to update their WM contents on every trial, in order to maintain the final count of each colour until the end of the block. Feedback about memory accuracy (the word “correct” or “incorrect” in white for 1500 ms) was provided after the response in each block to engage participants in the WM task. Participants' instructions, however, emphasized equal priority to temporal preparation and WM tasks.

For each task condition, participants completed seven blocks of 16 trials each of one temporal cue (e.g., early), and seven blocks of the remaining temporal cue (late). The order of presentation of early and late cue blocks was counterbalanced across participants within each single-task and dual-task condition. Half of the participants began with the single-task condition, and half began with the dual-task condition. The first block of each task condition was considered as practice. For each block, the validity proportion was of .75, i.e. 12 trials were valid trials in which the cue was early (or late) and the target appeared after the 1-s (or 3-s) time interval, whereas 4 trials were invalid, in which the cue was early (or late) and the target appeared after the 3-s (or 1-s) time interval. Participants received feedback on RT detection performance only during practice trials. A rest between blocks of trials was allowed. The whole session lasted about 45 minutes.

Design and data analysis. Experiment 1 constituted a within-participants design with the independent variables of Task (single-task versus dual-task), Validity (valid versus invalid), Previous interval (short versus long) and Current interval (short versus long). Participants' RT to respond to the target was the dependent variable. Temporal orienting effects were indexed by the main effect of Validity. Sequential effects were indexed by the main effect of Previous interval and their asymmetry by the interaction between Previous interval and Current interval.

Data from practice trials, the first trial of each block, trials with premature responses (i.e., responses before target onset: 2.4 %), trials with RT below 150 ms (0.3 %) and above 1000 ms (0.2 %), and trials without responses (0.8%) were rejected from the analysis. Mean RTs for each participant and condition were analysed by a repeated-measures ANOVA.

Results

In the WM task, the overall accuracy across participants to the colour memory test was 0.7[1].

In the temporal preparation task, the significant main effect of Task, *F*(1, 57) = 91.01, *p* <.001, showed that participants were slower in the dual-task condition than in the single-task condition. The main effect of Validity was also significant, *F*(1, 57) = 59.74, *p* <.001, with faster RTs for valid trials than for invalid trials. There was a significant interaction between Validity and Current interval, *F*(1, 57) = 37.72, *p* <.001. In line with previous temporal orienting studies (Nobre, 2001), the Validity effect was larger at the short interval (41 ms) than at the long interval (-7 ms), although it reached significance in both time intervals [*F*(1, 57) = 60.06, *p* <.001, *F*(1,57) = 3.86, *p* = .05, for the short and the long interval, respectively]. However, contrary to our prediction, the Validity effect was not modulated by Task condition (*F*s<1 for both Task x Validity and Task x Validity x Current interval interactions; see Figure 5).

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[1] One might argue that participants guessed the outcome of the secondary task as the expected value of the total number of colours in each block was 5.33 (16/3), which would led them to respond “5” systematically. This guessing strategy seems unlikely as participants were not informed or aware of the total number of trials in each block. Moreover, if participants were following this guessing strategy in a consistent way, we would expect no effects of the dual-task manipulation. In contrast, we found significant effects of dual-task interference on RT in the temporal preparation task in all the three experiments. This result confirmed that the dual-task manipulation was effective, that is, participants were actually engaged rather than neglecting the secondary task.

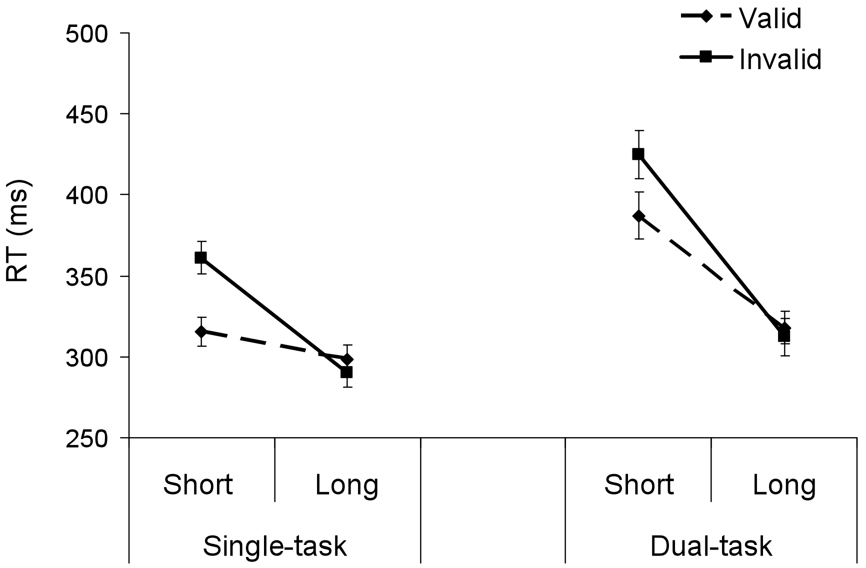

Figure 5. Mean RTs as a function of Task (single-task vs. dual-task), Validity (valid vs. invalid) and Current interval (short vs. long) for Experiment 1 (vertical bars represent standard error of the mean).

Regarding sequential effects, the main effect of Previous interval was significant, *F*(1, 57) = 264.8, *p* <.001, indicating that participants responded faster after a previous short interval than after a previous long interval. The significant interaction between Previous interval and Current interval, *F*(1,57) = 116.4, *p* <.001, replicated the typical asymmetry of sequential effects, with a larger effect of the previous interval at the current short interval (53 ms) than at the current long interval (12 ms), although it reached significance in both time intervals [*F*(1,57) = 371.8, *p*< .001, *F*(1,57) = 19.01, *p* <. 001, for the short and the long interval, respectively]. Crucially, sequential effects were not modulated by Task condition (see Figure 6), since the interactions involving Task and Previous interval factors were not statistically significant (*F*s <1 for both Task x Previous interval and Task x Previous interval x Current interval interactions).

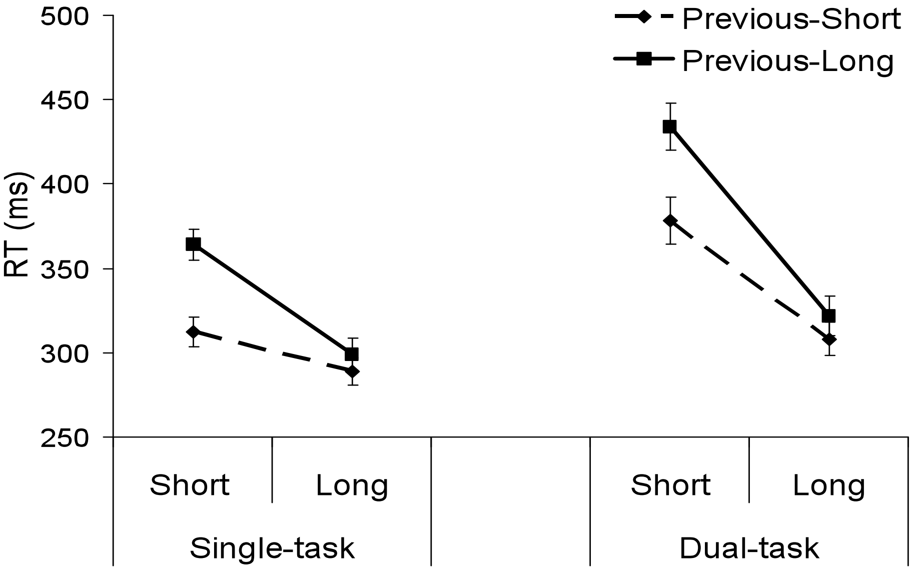

Figure 6. Mean RTs as a function of Task (single-task vs. dual-task), Previous interval (short vs. long) and Current interval (short vs. long) for Experiment 1 (vertical bars represent standard error of the mean).

Moreover, there was a significant main effect of Current interval, *F*(1, 57) = 281.5, *p* <.001, with participants responding faster at the long time interval as compared to the short time interval. The interaction between Task and Current interval was also significant, *F*(1, 57) = 75.23, *p* <.001. Further comparisons for this interaction[2] showed a greater difference in participants' RT between the single-task and the dual-task condition at the short interval (68 ms) as compared to the long interval (21 ms), with the task effect reaching statistical significance in both time intervals [*F*(1,57) = 120.6, *p*<.001 and *F*(1,57) = 22.22, *p* <.001, for the short and the long interval, respectively]. None of the remaining terms of the ANOVA reached statistical significance.

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[2] It is possible that the finding of larger dual-task interference at the short time interval as compared to the long time interval was a consequence of the experimental design used in our study. Since WM demands were placed into the temporal cue, one might argue that less time was available for memory updating and rehearsal of the colours at the short interval than at the long interval, thus explaining the Task by Current interval interaction. Although interesting, this aspect is beyond the scope of the present work (but see Van Lambalgen and Los, 2008, for empirical evidence on this issue), which was focused on the consequence of WM demands upon temporal orienting and sequential effects.

Discussion

The results of Experiment 1 showed a significant difference in temporal preparation performance between the single-task and the dual-task condition: participants' response time to the target was impaired by the concurrent colour counting task. This finding confirmed that our manipulation of WM was effective and that temporal preparation is sensitive to extra demands of executive control. Unexpectedly, however, both temporal orienting and sequential effects survived to dual-task interference. In fact, contrary to our prediction on temporal orienting, the validity effect was of similar magnitude under both the single-task and the dual-task condition.

As temporal cues were manipulated in a blocked design, it is possible that temporal orienting was contaminated by the presence of strong sequential effects. That is, the early block and the late block could be biased by the high frequency of short and long intertrial sequences, respectively, so that the final shape of cueing effects would stem from sequential transitions over successive trials rather than from temporal orienting. This would account for the lack of dual-task interference on both temporal orienting and sequential effects. To explore this possibility, we made a reanalysis of the data of Experiment 1 with the factors of Task, Temporal expectancy, Previous interval and Current interval, which revealed a significant interaction between Temporal expectancy and Current interval, $F(1, 57) = 59.74$, $p < .001$ (i.e., temporal orienting effects) that, crucially, was independent of sequential effects (Temporal expectancy x Previous interval x Current interval: $F<1$). This result replicates the findings by Correa et al. (2004, 2006), suggesting that the contribution of temporal orienting is independent from the presence of sequential effects in the context of a blocked-manipulation of temporal expectancies.

A more plausible explanation for the finding that temporal orienting survived to dual-task interference considers that the cueing manipulation employed in this experiment was confounded with a foreperiod (i.e., the time interval between the cue and the target) distribution effect. Note that the early block contained 75% of short foreperiods and 25% of long foreperiods (and the reverse for the late block). Accordingly, temporal predictions could be built up on the basis of the foreperiod distribution, rather than on the basis of symbolic cues. This redundancy in the source of temporal predictions may have helped overcome interference under dual-task conditions, as attention to cues could prioritize colour over temporal information, which was already afforded by the blocked design. Hence, the amount of resources available in Experiment 1 was sufficiently high to orient attention in time while performing concurrently the WM task. This explanation is supported by the finding that temporal orienting effects in choice-RT tasks are larger when temporal expectancy is manipulated between blocks rather than on a trial-by-trial basis (Correa et al., 2004), which shows that generating a single temporal expectancy across a block of trials regardless of symbolic cues is less demanding than generating a new temporal expectancy after interpreting the meaning of the temporal cue presented on each trial.

In sum, data from Experiment 1 suggest that temporal orienting based on a blocked design may involve automatic processing, but leave open the question regarding the controlled versus the automatic nature of temporal orienting based on symbolic cueing. To address this issue and to avoid the confounding foreperiod distribution effects mentioned above, in Experiment 2 we manipulated temporal expectancy driven by symbolic cues on a trial-by-trial basis. Assuming that the generation of a new temporal expectancy on each trial would engage a larger amount of controlled processing, thus competing for limited resources with the WM task, we expected to observe reduced temporal orienting effects under the dual-task condition as compared to the single-task condition.

Experiment 2

Experiment 2 was conducted to test whether dual-task requirements, which had no effect on temporal orienting based upon a blocked manipulation of expectancies in Experiment 1, may interfere with temporal orienting as participants had to update and shift their temporal expectancy on each trial.

Method

Participants. Twenty-four new undergraduates from the University of Granada (twenty-one females, one left-handed, age range: 18-26 years old) participated in Experiment 2.

Apparatus, stimuli and procedure. The apparatus, stimuli and procedure were the same as those used in Experiment 1 with one critical difference: temporal cues were manipulated on a trial-by-trial basis rather than between-blocks of trials. Thus, trials with short lines and trials with long lines (cueing early and late target onsets, respectively) were randomly intermixed within each block.

At the beginning of the experiment, participants were given a short training session to learn the cue-temporal interval contingency, which consisted of four blocks of 16 trials each (100% valid; cf. Correa et al., 2004). After the training session, half of the participants began with the single-task condition, and half began with the dual-task condition. There were seven blocks for each task condition. The first block of each task condition was considered as practice. Each experimental block consisted of 8 early-cue trials and 8 late-cue trials (cue validity: 75%). The whole session lasted about 30 minutes.

Design and data analysis. Similarly to Experiment 1, the independent variables were all manipulated within participants, and included Task (single-task versus dual-task), Validity (valid versus invalid), Previous interval (short versus long), and Current interval (short versus long). Participants' RT to respond to the target was the dependent variable.

Data from practice trials, the first trial of each block, trials involving premature responses (i.e., responses before target onset: 3 %), trials with RT below 150 ms (0.3 %) and above 1000 ms (0.1 %), and trials without responses (0.6 %) were rejected from the analysis. Mean RTs for each participant and condition were analysed by a repeated-measures ANOVA.

Results

In the WM task, the overall accuracy across participants to the colour memory test was 0.62.

In the temporal preparation task, the ANOVA revealed slower participants' RT for the dual-task condition than for the single-task condition, which led to a main effect of Task, $F(1, 23) = 44.89$, $p < .001$. Crucially, in contrast to Experiment 1, the Validity effect was modulated by Task condition, as shown by a significant interaction between Task and Validity, $F(1, 23) = 5.4$, $p = .029$. Planned comparisons for this interaction revealed that participants' RT was faster for valid trials than for invalid trials only in the single-task condition, *F*(1,23) = 9.5, *p*= .005, but not in the dual-task condition, *F* <1. This finding was also supported by a significant Task x Validity x Current interval interaction, *F*(1, 23) = 5.6, *p*= .027, which showed that at the short interval the interaction between Task and Validity was significant, *F*(1, 23) = 7.7, *p* = .01, but not at the long interval, *F*<1 (see Figure 7). Specifically, at the short interval temporal orienting effects were significant only in the single-task condition [31 ms, *F*(1,23) = 17.2, *p* <. 001] but not in the dual-task condition [5 ms, *F* <1]. At the long interval, no temporal orienting effects were observed in either the single-task or in the dual-task condition, which was expected according to the typical finding of interaction between Validity and Current interval, *F*(1, 23) = 10.16, *p* =.004, with a significant Validity effect at the short interval [13 ms, *F*(1, 23) = 7.2, *p* =.01] but not at the long interval [-6 ms, *F*(1, 23) = 2.7, *p* = .1].

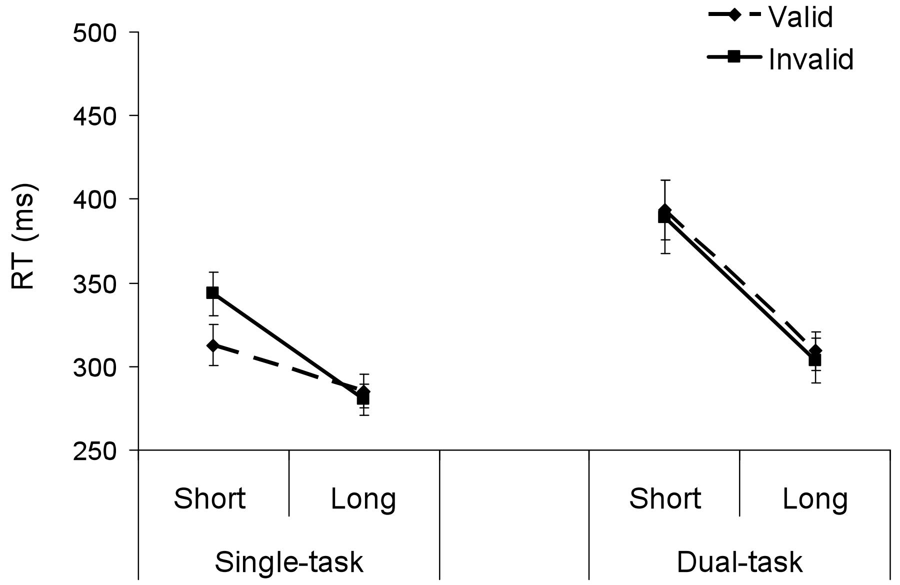

Figure 7. Mean RTs as a function of Task (single-task vs. dual-task), Validity (valid vs. invalid) and Current interval (short vs. long) for Experiment 2 (vertical bars represent standard error of the mean).

The analysis of sequential effects replicated Experiment 1, as both the main effect of Previous interval and the interaction between Previous interval and Current interval were significant, F(1, 23) = 57.2, p <.001 and F(1, 23) = 46.9, p <.001, respectively. The Task x Previous interval interaction was significant, *F*(1, 23) = 5.7, *p*= .026, showing a greater effect of the previous interval in the dual-task condition, *F*(1,23) = 38.8, *p*< .001, as compared to the single-task condition, *F*(1,23) = 27.2, *p*< .001. The Task x Previous interval x Current interval interaction was also significant, *F*(1,23) = 10.7, *p*= .003, showing larger sequential effects (RT on Previous long interval minus RT on Previous short interval) at the short interval in the dual-task condition than in the single-task condition, *F*(1, 23) = 13.2, *p* =.001 (see Figure 8). It is important to remark that the Previous interval x Current interval interaction was significant in both task conditions, *F*(1,23) = 59.8, *p* <.001, and *F*(1,23) = 32.3, *p* <.001, respectively.

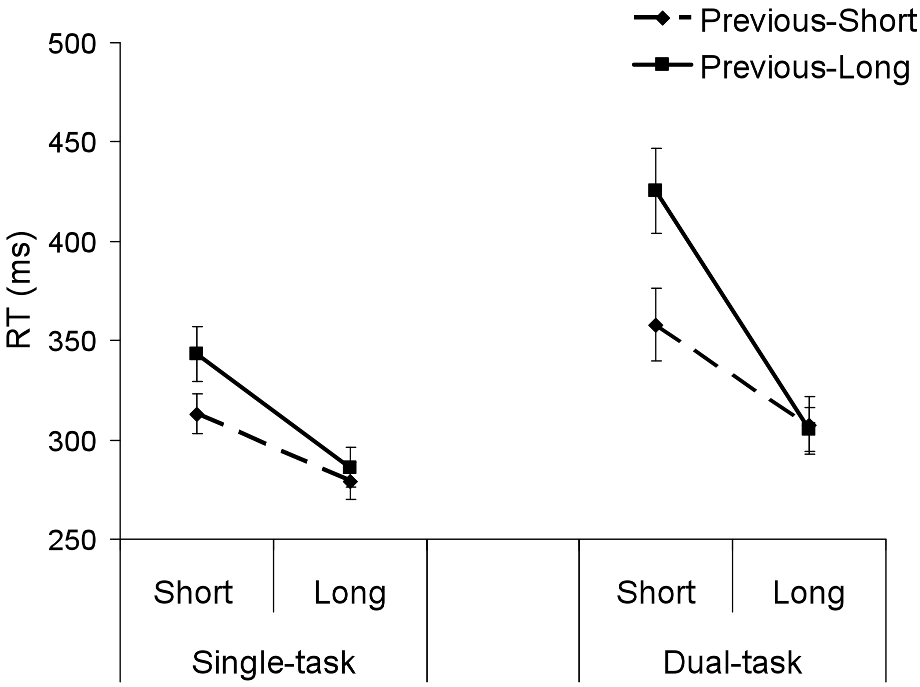

Figure 8. Mean RTs as a function of Task (single-task vs. dual-task), Previous interval (short vs. long) and Current interval (short vs. long) for Experiment 2 (vertical bars represent standard error of the mean).

Finally, the main effect of Current interval was significant, *F*(1,23) = 127.9, *p* <.001, with participants responding faster at the long interval as compared to the short interval. The significant Task x Current interval interaction was also replicated, *F*(1, 23) = 23.7, *p* <.001, with a greater difference in participants' RT between the single-task and the dual-task condition at the short interval (63 ms) as compared to the long interval

(24 ms), although the task effect reached statistical significance in both time intervals [*F*(1,23)= 53.3, $p < .0001$, *F*(1,23) = 13.07, *p*= .001, for the short and the long interval, respectively].

None of the other terms in the ANOVA was statistically significant except for the Validity x Previous interval interaction, *F*(1, 23) = 7.9, *p*= .01, showing larger validity effects after a previous short interval versus a previous long interval [*F*(1,23) = 6.2, *p*= .02, *F*(1,23) = 2.4, *p*= .01, respectively].

Discussion

Experiment 2 showed that dual-task requirements impaired temporal orienting effects significantly when temporal cues changed randomly from trial to trial. Participants' RT was indeed faster for valid trials as compared to invalid trials only in the single-task condition. This result suggests that participants were unable to prepare voluntarily when executive resources were depleted by the generation of a new temporal expectancy on each trial and the concurrent WM task.

The Task x Previous interval x Current interval interaction reached statistical significance in this experiment, revealing stronger asymmetric sequential effects in the dual-task condition than in the single-task condition. This finding is therefore convergent with Experiment 1, as sequential effects were neither eliminated nor reduced by the secondary task. In the dual-task condition of this experiment, it is worth noting that the increment of sequential effects on one hand, and the disruption of temporal orienting effects on the other hand lend further support to the finding that temporal orienting and sequential effects involve dissociable processes (Correa et al., 2004; Correa et al., 2006; Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001). Attention was not necessary for the occurrence of sequential effects since they were present by default regardless of voluntary effort, and, as highlighted by the results of Experiment 2, they were even larger in conditions where attention was divided between two demanding tasks (cf. Los & Van den Heuvel, 2001). On the contrary, temporal orienting (manipulated within-blocks of trials) required attentional control, so that when participants were forced to divert their attention from the temporal preparation task by simultaneously performing the WM task, temporal orienting effects were completely abolished.

The results of Experiment 2 confirmed that the presence of a secondary task interfered with participants' ability to orient attention in the temporal domain. However, this latter finding could also be explained by interference between the interpretation of the temporal cue as signalling an early and late target onset and the processing of cue colour information for the memory task**.** Specifically, the absence of temporal orienting effects in Experiment 2 might be due to the fact that participants neglected to process the meaning of the temporal cue because they were engaged in updating the colour information. This possibility was tested in Experiment 3.

Experiment 3

Experiment 3 was similar to Experiment 2 except in one critical aspect: the temporal cues were always displayed in gray in order to avoid any possible confound with the WM task. WM was loaded at the beginning of each trial by presenting participants with one of three coloured (red, green or blue) stars. As in Experiments 1 and 2, we manipulated WM demands by having participants remember and report the final count of each colour at the end of every block. However, differently from Experiment 2, this design ensured that the updating of the count in WM would not interfere with the processing and interpretation of the temporal cues. On the premises that temporal orienting relies on controlled processing, we expected Experiment 3 to replicate the main finding of Experiment 2, that is, a significant interaction between Task and Validity.

Method

Participants. Twenty-eight new undergraduates from the University of Granada (twenty-three females, five left-handed, age range: 18-46 years old) participated in Experiment 3.

Apparatus, stimuli and procedure. Everything was the same as in Experiment 2 except for the following: 1) the temporal cues were always displayed in gray; and 2) the memory stimuli consisted of three coloured (red, green and blue) stars (1.31° x 1.01°

visual angle). In each trial a blank screen was presented for 50 ms, followed by a 200-ms period which was used to display the coloured star. After the presentation of the memory stimulus, there was a random interval ranging from 500 and 1000 ms before the presentation of the temporal cue.

Design and data analysis. The independent variables were all manipulated within participants, and included Task (single-task versus dual-task), Validity (valid versus invalid), Previous interval (short versus long), and Current interval (short versus long). Participants' RT to respond to the target was the dependent variable.

Data from practice trials, the first trial of each block, trials involving premature responses (i.e., responses before target onset: 1.2 %), trials with RT below 150 ms (0.2%) and above 1000 ms (0.2 %), and trials without responses (0.9 %) were rejected from the analysis. Mean RTs for each participant and condition were analysed by a repeated-measures ANOVA.

Results

In the WM task, the overall accuracy across participants to the colour memory test was 0.64.

In the temporal preparation task, the ANOVA replicated the significant effects of Task, $F(1, 27) = 40.6$, $p < .001$, Validity, $F(1, 27) = 17.44$, $p < .001$, and the interaction between Validity and Current interval, $F(1, 27) = 27.82$, $p < .001$. Most relevant, there was a significant interaction between Task and Validity, $F(1, 27) = 4.8$, $p = .03$, with the validity effect being significant only in the single-task condition (20 ms, $F(1, 27) = 30.41$, $p < .001$), but not in the dual-task condition (5 ms, $F < 1$).

Although the Task x Validity x Current interval interaction was not significant, $F(1, 27) = 1.65$, $p = .2$, hypothesis-driven planned comparisons (see Rutherford, 2001; Keppel & Zedeck, 1989) at the short interval revealed that the validity effect was half size smaller in the dual-task condition than in the single-task condition (21 ms vs. 43 ms), Task x Validity: $F(1, 27) = 4.03$, $p = .05$ (this interaction was not significant at the long interval, $p = .2$). It is important to note that the validity effect at the short interval was significant for both the single-task, $F(1, 27) = 36.24$, $p < .001$, and the dual-task condition, $F(1, 27) = 5.58$, $p = .02$ (see Figure 9).

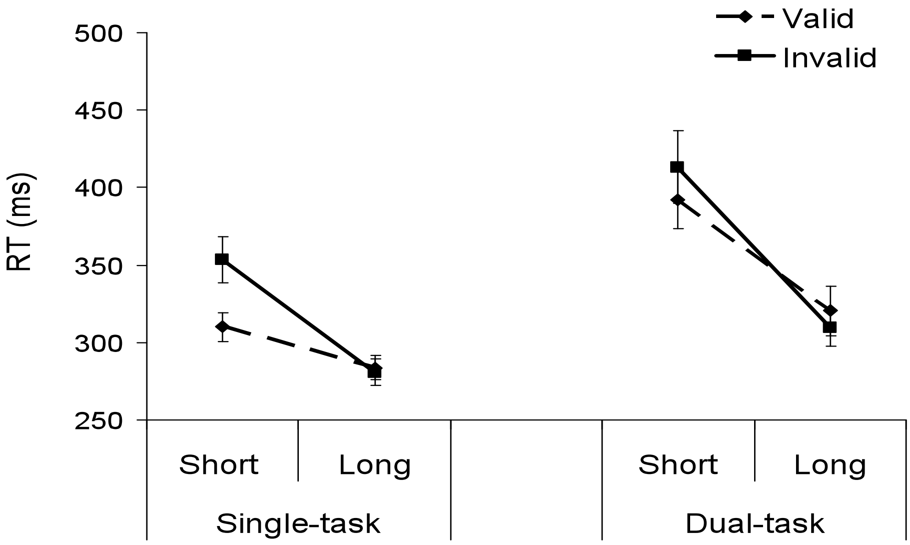

Figure 9. Mean RTs as a function of Task (single-task vs. dual-task), Validity (valid vs. invalid) and Current interval (short vs. long) for Experiment 3 (vertical bars represent standard error of the mean).

The analysis of sequential effects replicated Experiment 1, with significant effects of Current interval, *F*(1, 27) = 156.2, *p* <.001, Previous interval, *F*(1, 27) = 75.04, *p* <.001, and interaction between Previous interval and Current interval, *F*(1, 27) = 46.55, *p* <.001. The critical finding was that sequential effects were not attenuated by dual-task demands (*F*s <1 for both Task x Previous interval and Task x Previous interval x Current interval interactions; see Figure 10). None of the other terms in the ANOVA was statistically significant except for the Task x Current interval interaction, *F* (1, 27) = 16.7, *p* <.001.

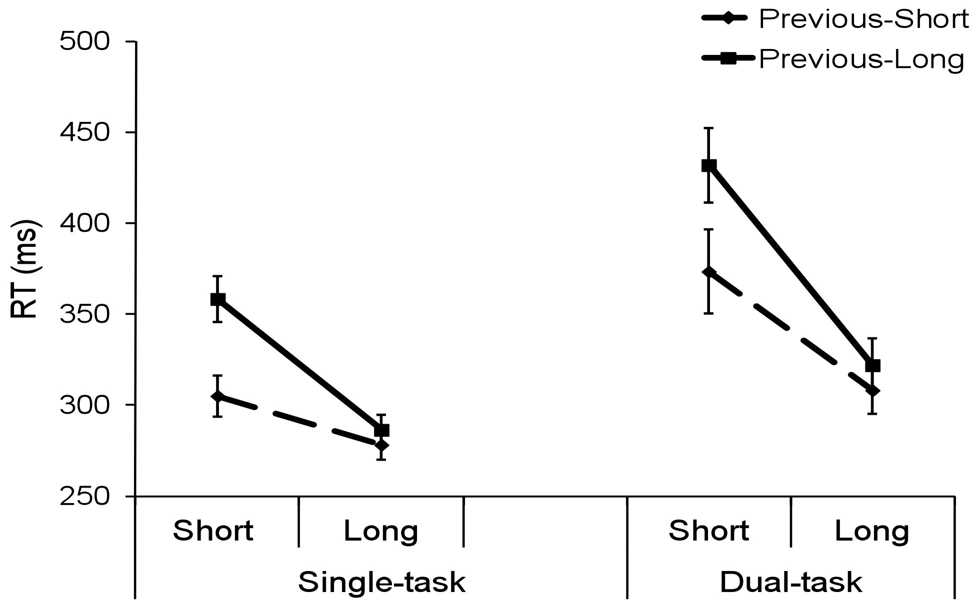

Figure 10. Mean RTs as a function of Task (single-task vs. dual-task), Previous interval (short vs. long) and Current interval (short vs. long) for Experiment 3 (vertical bars represent standard error of the mean).

Discussion

The results from Experiment 3 showed that sequential effects were not reduced by the secondary memory task, a finding that supports their automatic nature. In contrast, temporal orienting effects were larger in the single-task condition as compared to the dual-task condition. This finding renders unlikely the possibility that the absence of temporal orienting effects in Experiment 2 was simply due to interference between the updating of the count in WM and the interpretation of the temporal cues, because in the present experiment the temporal preparation task and the WM task did not share the same stimulus. In this regard, it is important to note that the results of Experiments 2 and 3 differed in one critical aspect. Namely, the validity effect at the short interval was completely abolished by dual-task demands in Experiment 2, while it was significant, although reduced, with respect to the single task condition in Experiment 3. This finding confirmed that in Experiment 3 participants were engaged in processing the meaning of the temporal cue, which suggests that the reduction of the validity effect was due to dual-task interference and the fact that temporal orienting relies on controlled processing.

General Discussion

In three experiments, a dual-task approach was used to directly test the nature of the processes involved in temporal preparation. The logic of our design was based on the criterion that controlled processing would be reduced by a demanding secondary task, whereas automatic processing would not be attenuated by such a dual-task context (e.g., Logan, 1979; Posner & Snyder, 1975). The results of Experiments 1-3 showed that temporal orienting and sequential effects could be behaviourally dissociated by using a dual-task paradigm. The current data provide direct support to the idea that both controlled and automatic processes may contribute independently to the development of temporal preparation (Correa, 2010; Los and Van den Heuvel, 2001).

Temporal orienting effects were completely abolished under dual-task conditions in Experiment 2, where the same stimulus (the temporal cue) elicited updating of both WM and temporal expectancy on a trial-by-trial basis. Separating the memory cue from the temporal cue in Experiment 3 did not completely eliminate temporal orienting effects on short-interval dual-task trials, proving that participants were actually processing the meaning of the temporal cue. However, despite encoding of temporal cues was enabled in this experiment, temporal orienting effects were significantly reduced in the dual-task condition as compared to the single-task condition. Taken together, these findings suggest a gradation of the competition for attentional resources between temporal preparation and WM tasks across the three experiments reported in the present manuscript (cf. Logan, 1978, 1979). As Figure 11 shows, maximal competition would have occurred in Experiment 2 (updating of WM and temporal expectancy took place simultaneously), followed by Experiment 3 (the two updating processes were separated in time), and Experiment 1 (only updating of WM but not of temporal expectancy was required on each trial).

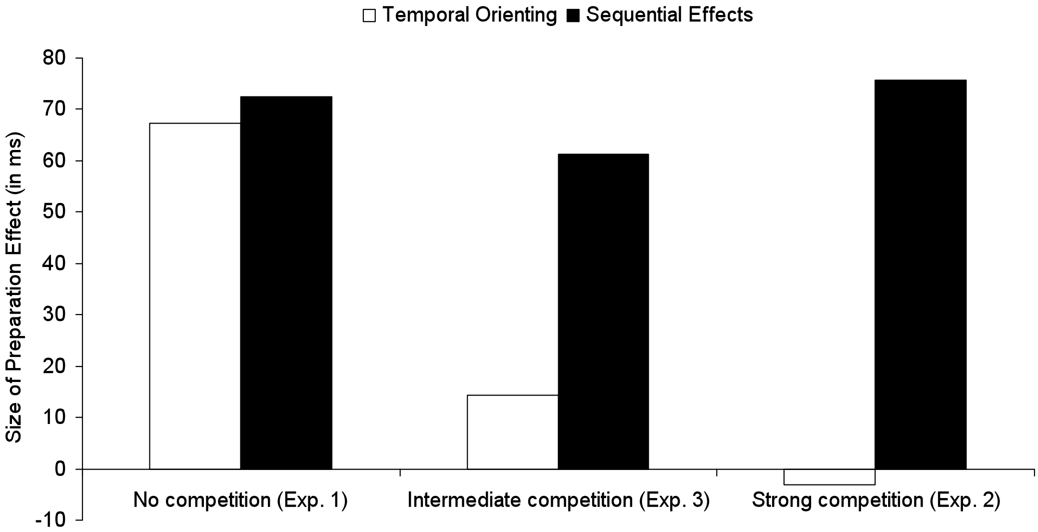

Figure 11. Competition between updating of working memory versus temporal expectancy for temporal orienting and sequential effects across the three experiments. The size of the preparation effects was computed for both temporal orienting (RT-invalid minus RT-valid) and sequential effects (RT-previous long minus RT-previous short) at the short interval. Data are from the dual-task condition.

This pattern of results supports the idea that the distinction between controlled and automatic processing should be perceived as a continuum rather than a strict dichotomy. Such a view is in agreement with earlier studies showing that controlled processing may develop into automatic processing after practice at a task (Posner & Snyder, 1975; Shiffrin & Schneider, 1977), and that automatic processing is not cognitively impenetrable or "encapsulated" (cf. Fodor, 1983) since it may be susceptible of modulation by controlled factors (see Ruz & Lupiáñez, 2002, for an example on the attentional capture literature). Our data extend these observations in the temporal preparation domain by showing that the balance between controlled and automatic processing in temporal orienting of attention can be affected by several factors, such as the way in which temporal information is provided.

To sum up, the results of the three experiments presented here provide the first behavioural evidence that a different amount of executive resources may be recruited by instructing participants to shift their temporal expectancy across trials as compared to focus their attention along the whole block (cf. Correa et al., 2004, 2006). This is in line with research showing that temporal orienting involves different brain areas in between-blocks as compared to within-blocks manipulation of temporal expectancies. Namely, a recent neuropsychological study has found a clear lateralization of temporal orienting effects in the context of a blocked-design in the right prefrontal cortex, while no temporal orienting deficit was observed in patients with left frontal lesions (Triviño et al., 2010). Conversely, another functional MRI study has reported the involvement of left prefrontal structures when temporal cues were manipulated on a trial-by-trial basis, suggesting that updating and shifting the temporal information provided by the cue may engage different neural circuits (Coull & Nobre, 1998).

In contrast to temporal orienting, sequential effects survived to dual-task interference in Experiments 1-3, as they were neither eliminated nor reduced by concurrent task demands. This finding supports the dissociation between temporal orienting and sequential effects and reinforces the hypothesis that sequential effects are generated by automatic processing (see Correa et al., 2004; Correa et al., 2006; Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001). In line with this latter idea, an interesting finding of Experiment 2 was the increased magnitude of sequential effects under dual-task relative to single-task conditions. It would appear that the high attentional demands and competition between temporal orienting and memory tasks in Experiment 2 resulted in an enhancement of the automatic processing responsible for sequential effects. Although plausible, however, such idea deserves further investigation as a pattern of enhanced sequential effects under dual-task conditions was observed only in Experiment 2. Moreover, a dual-task study by Van Lambalgen and Los (2008) reported that extra processing demands interfered with sequential effects by reducing, instead of enhancing, their asymmetry. Future research shall address the discrepancy between Van Lambalgen and Los's study (2008) and the present findings by testing sequential effects across different secondary tasks, in order to explore under which conditions they may interact or not with concurrent task demands.

In conclusion, the present study dissociated the involvement of automatic and controlled processes in temporal preparation, and proved for the first time the effectiveness of dual-task methodology in investigating the nature of both temporal orienting and sequential effects. A challenge for future research would be to specify the boundary conditions determining the expression of automatic and controlled temporal preparation processing.

Chapter V: 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 N2 amplitude and P3 latency only under single-task, but not under dual-task conditions. Differently from temporal orienting, sequential effects were also observed at the early target-locked P1 and N1 potentials. Crucially, only the P1 modulation survived to 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.

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; Nobre, 2001; Coull & Nobre, 1998), participants have to respond as fast as possible 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 faster 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 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 (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 lenghtening 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 simbolic 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, & Lupiañez, 2010).

The neural substrates underlying temporal orienting effects have been widely investigated using event related potential measures (ERPs; e.g., Correa & Nobre, 2008, Correa, Lupiañez, Madrid, & Tudela, 2006; Doherty, Rao, Mesulam, & Nobre, 2005; Griffin, Miniussi, & Nobre, 2002; Lampar & Lange, 2011; Lange, 2011; 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 N2 and the P3. The CNV is a slow negative wave occurring during the preparatory interval between a warning signal and an impeding 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 expectany cue in relation to a late expectancy cue at the moment of likely early target onset (Los & Heslenfeld, 2005; Loveless & Sandford, 1974; Miniussi, Wilding, Coull, & Nobre, 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 N2 and the P3 (see Folstein & Van Petten, 2008; Polich, 2007, for reviews on the N2 and P3 potentials, respectively). The N2 amplitude is attenuated and the P3 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 N2 attenuation may reflect "the temporal maintenance of response inhibition to prevent responding at inappropriate times" (Correa & Nobre, 2008, p. 1654), while the reduced P3 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 P1 and N1 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 et al., 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 research (Capizzi, Sanabria, & Correa, 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., 2011; 2010). 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 this prediction, our results (Capizzi et al., 2012) reported reduced validity effects in the dual-task condition as compared to the single-task condition. In contrast to temporal orienting, sequential effects survived to dual-task interference, as they were neither eliminated nor reduced by concurrent task demands.

These findings were taken as evidence that, differently from sequential effects, temporal orienting relies on controlled processing, so that when cognitive demands were increased by the secondary working memory task with respect to the single-task condition, participants did not longer benefit from the predictive information provided by the temporal cue. However, the specific locus of interference between temporal orienting and concurrent dual-task demands cannot be established by a purely behavioural approach. One might wonder, for instance, whether the disruption of temporal orienting effects shown by Capizzi et al. (2012) arose at response stages, which have been selectively linked to temporal orienting of attention (Nobre, 2001), or whether dual-task interference acted unspecifically on perceptual levels since temporal orienting and working memory tasks shared the same visual modality. In addition, it makes sense to wonder whether the presence of a dual-task context might already interfere with preparatory activity preceding the onset of the target, as indexed by the CNV potential. To address these questions, the current study exploited the high temporal resolution of ERPs with the main aim of identifying at which stages of information processing the concurrent performance of a working memory task would interfere with temporal orienting of attention. In addition, we tested whether temporal orienting and sequential effects would act on similar or different levels of target processing.

Our predictions were as follows. With respect to temporal orienting effects, we reasoned that if the dual-task manipulation would interfere selectively with temporal orienting, then such interference should be reflected in a lower modulation of the CNV amplitude under dual-task relative to single-task conditions. Moreover, we expected to observe a significant impairment of the typical neural correlates of temporal orienting, with no attenuation of the N2 amplitude and P3 latency by temporal expectancy under dual-task relative to single-task conditions.

Regarding sequential effects, we sought to replicate Los and Heslenfeld's (2005) results of a more negative CNV when the previous interval was short as compared to when it was long. Building on this study which revealed additive influences of temporal orienting and sequential effects on preparatory processes, we also predicted a similar modulation of late target processing stages for the two temporal effects. Importantly, however, only the ERP pattern associated to sequential effects (but not to temporal orienting) should be unaffected by dual-task demands.

Method

Participants. Twenty-two students from the University of Granada took part in the experiment in exchange for course credits or cash payment of 15 Euro. All participants gave informed consent prior to their inclusion in the study. They had normal or corrected-to-normal visual acuity and reported having normal colour vision. The study was approved by the local ethics committee and was conducted according to the guidelines of the Declaration of Helsinki. Data from six participants were discarded because of excessive eye-movements or other artefacts. The remaining 16 participants (age range: 22-35 years, 2 men) were used for both behavioural and ERP analyses. All but three participants were right-handed.

Stimuli and task. Stimulus presentation and response collection were controlled by an Intel Core 2 Duo personal computer connected to a 17" LCD monitor. This computer, running Biological E-prime software (Schneider, Eschman, & Zuccolotto, 2002), was connected to a Macintosh computer (Power PC G5) that recorded continuous EEG. All stimuli were presented centrally against a black background. The temporal cue consisted of a short (3.4º x 1.3º visual angle) or long (7.5º x 1.3º) line displayed either in 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).

Participants were tested in a silent, dimly illuminated and electrically shielded room. Each trial began with the presentation of a blank screen for a random duration between 500 and 1000 ms (see Figure 12-A). The temporal cue, displayed in one of three colours (red, green, or blue), was then presented for 750 ms. Each colour was randomly generated at the beginning of each trial with the same probability of appearance. In the first experimental session (i.e., single-task condition), participants were told that the colour of the temporal cue was task-irrelevant and should therefore ignore it. Following the temporal cue, the screen remained blank for a variable delay of either 1000 or 2000 ms, depending on the time interval for that trial. After the time interval elapsed, the target stimulus was presented for 100 ms and then disappeared. Participants had to respond to every target onset as quickly as possible by pressing either the leftmost or rightmost key on a 4-key numeric keypad with their left or right index finger, respectively. The assignment of the target to response keys was counterbalanced across blocks. A visual feedback message was displayed for 500 ms either in case of an anticipated response ("wait for the target") or if no response was made within 1100 ms after target offset ("respond earlier"). Following the response to the target, or after 1100 ms in case o f a missed response, the next trial began.

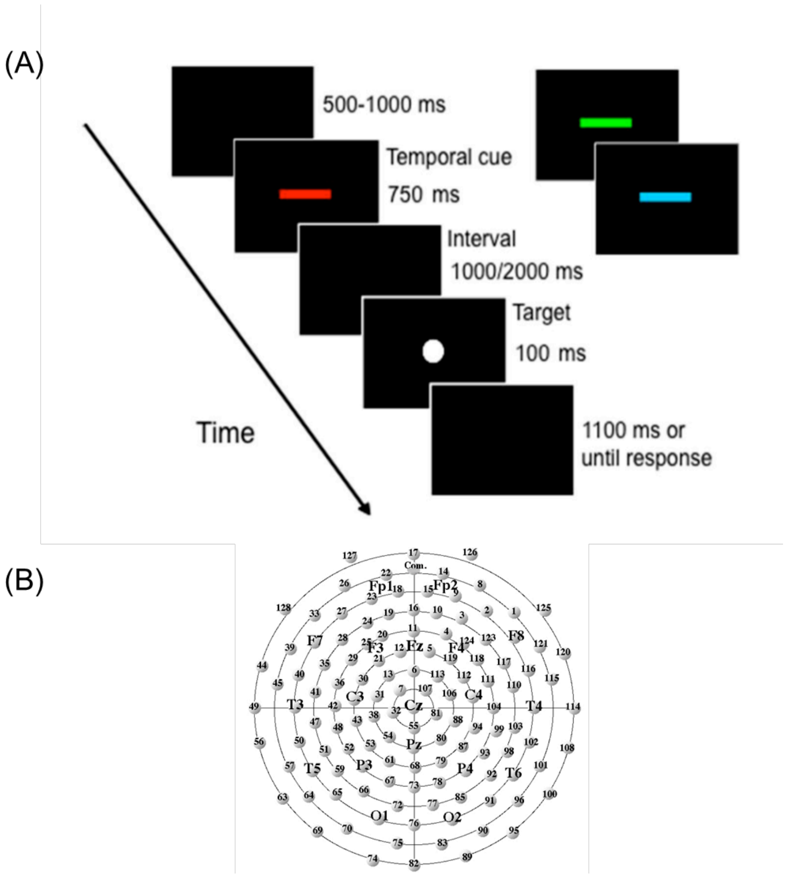


Figure 12. (A) Schematic representation of events in a trial. The colour of the temporal cue could be red, green or blue. (B) Sketch of the electrodes distribution around the scalp as viewed from above (the top of the figure represents the frontal area).

In the dual-task condition, the temporal orienting task remained the same as that described above. The only difference with respect to the single-task condition was the addition of the concurrent working memory task. The working memory task required participants to count and remember how many times each temporal cue colour appeared during a block of trials. At the end of the block, one of the three colours was randomly chosen (e.g., "*red*") and participants said aloud how many times that colour had been presented. The experimenter then typed the response. Each colour was equally probable to be selected for the memory test. This task encouraged participants to update their working memory contents on every trial, in order to maintain the final count of each colour until the end of the block. Feedback about memory accuracy (the word "correct" or "incorrect" in white for 1500 ms) was provided after the response in each block to engage participants in the working memory task. Participants' instructions, however, emphasised equal priority to temporal orienting and working memory tasks.

At the beginning of the experiment, participants were given a short training session to learn the cue-time interval contingency, which consisted of two blocks of 16 trials each (100% valid; cf. Correa et al., 2006). Participants were explicitly informed that the temporal cue would help them to predict the occurrence of the upcoming target. After the training session, participants completed thirty-one blocks of 16 trials each of the single-task condition, followed by thirty-one blocks of the dual-task condition. Presentation of the single-task condition took place before the dual-task condition, which was separated from the previous session by 1 or 2 days. The goal of this procedure was to familiarise participants with the temporal orienting task before performing the working memory task. In this way, we aimed to strengthen the processing of the temporal cues in the first (single-task) session in order to consolidate them for the second (dual-task) session.

The first block of each task condition was considered as practice. Each experimental block consisted of 8 early-cue trials and 8 late-cue trials. On early-cue trials, 6 were valid trials, in which the target appeared after 1000 ms, and 2 were invalid trials, in which the target appeared after 2000 ms (cue validity: 75%). Likewise, on late-cue trials, 6 were valid trials, in which the target appeared after the 2000 ms, and 2 were invalid trials, in which the target appeared after 1000 ms. Participants received feedback on RT performance only during practice trials. A rest between blocks of trials was allowed. The whole experimental session lasted about 90 minutes.

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 12-B), connected to an AC-coupled high-input impedance amplifier (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 Electrical Geodesics high-input impedance amplifiers. Gain and zero calibration were performed prior to the 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.

ERP analysis. Continuous raw data were filtered offline using a 30-Hz low-pass filter. Separate epochs were constructed for cues (between -100 and 1750 ms relative to cue onset) and targets (between -200 and 600 ms relative to target onset). The period of 100 ms preceding cue onset was used to calculate the baseline for the cue analysis. A strict baseline correction was instead performed for the target analysis, [−200, 50] ms, in order to minimize distortion of the ERP averages due to the overlap from previous events (see Woldorff, 1993). The segmented epochs were then submitted to software algorithms for identification of artefacts (Eye blink and Eye movement threshold: deflections exceeding ±70 μV relative to baseline in EOG channels; other artifacts threshold: deflections exceeding ±80 μV relative to baseline in any channel). Individual bad channels were replaced on a trial-by-trial basis with a spherical spline algorithm (Perrin, Pernier, Bertrand, & Echallier, 1989), but trials were discarded if more than ten channels were bad. In addition, trials that did not meet the criteria set for behavioural analyses were rejected. A minimum of 30 trials per condition was required to ensure a sufficient signal-to-noise ratio.

Artefact-free epochs were then re-referenced off-line to the average in order to eliminate the effects of reference-site activity and to generate an accurate estimation of the scalp topography of the recorded electrical fields (Tucker, Liotti, Potts, Russell, &

Posner, 1994). Separate grand average waveforms were constructed according to both cues and targets categories. ERP waves elicited by the cue gave rise to four conditions: previous short – early cue, previous long – early cue, previous short–late cue, previous long – late cue, according to whether early and late cue trials were preceded by a short or long interval. Cue validity was not taken into account since this was not relevant until the appearance of the target.

ERPs evoked by targets were separated into two categories: 1) valid and invalid trials, regardless of the previous interval condition; and 2) previous short and previous long interval trials, regardless of the validity condition (note that the small number of invalid trials did not allow combining the two conditions into a single analysis).

Given that all analyses were restricted to targets appearing at the short time interval in order to avoid any influence from foreperiod effects at the long time interval (i.e., if the target does not appear after the short interval, it would appear after the long interval with full probability; Coull, 2009; Niemi, & Näätänen, 1981), the valid condition included trials in which the cue was 'early' and the target appeared at the short interval, whereas the invalid condition included trials in which the cue was 'late' and the target appeared at the short interval. Following the same criteria for the sequential effects analysis, the previous short interval condition included trials in which the previous interval was 'short' and the target appeared at the short interval, while the previous long interval condition included trials in which the previous interval was 'long' and the target appeared at the short interval.

For all analyses, amplitude was calculated as the mean voltage in a specificied temporal window and electrodes site. Such windows and sites were chosen on the basis of visual inspection of the grand average waveforms and according to prior literature. The latency associated to the maximum peak was analysed only for the P3 potential within the same temporal window and electrodes site as those used for the P3 amplitude. The Greenhouse-Geisser correction was applied when sphericity was violated (Jennings and Wood 1976). Corrected probability values are reported.

Cue-locked ERPs. The mean CNV amplitude was analysed after cue offset (note that the temporal cue was presented for 750 ms) over frontal and central regions (*left*: 7, 13, C1, 32; *midline*: FCz, Cz; *right*: 107, 113, C2, 81). Five time bins of 200 ms each were selected for statistical analysis: (1) 750–950 ms, (2) 950–1150 ms, (3) 1150-1350,

(4) 1350-1550, and (5) 1550-1750 ms. Amplitude differences were tested using a five-way ANOVA with the within-participants factors of Time bin (1, 2, 3, 4, 5), Task (single-task, dual-task), Cue (early, late), Previous interval (short, long) and Electrodes site (left, midline, right). Significant effects of Electrodes site were reported only if they interacted with either Cue, Previous interval, or both.

Target-locked ERPs.

Temporal orienting. The P1 and N1 potentials were measured over posterior electrodes (*left:* P1, PO3, PO7, O1, 67; *midline:* Pz, POz, 73; *right:* P2, PO4, PO8, O2, 78) beetween 110-150 ms and 160-200 ms, respectively.

The N2 potential was measured over parietal regions (*left*: 54, P3, P1; *midline*: CPz, Pz, POz; *right*: 80, P4, P2) between 240-280 ms. The P3 was analysed over central and parietal electrodes sites (*left*: 7, C1, CP1, 54, 32; *midline*: Cz, CPz, Pz; *right*: 107, C2, CP2, 80, 81) between 340-430 ms.

Separate repeated-measures ANOVAs were conducted on the mean amplitude of each target-locked ERP and on the latency of the P3 with Task (single-task, dual-task), Validity (valid, invalid) and Electrodes site (left, midline, right) as within-participants factors. Significant effects of Electrodes site were reported only if they interacted with Validity.

Sequential effects. The analysis of sequential effects was conducted on the same ERPs, including the same temporal windows and electrodes sites as those employed in the temporal orienting analysis. Separate repeated-measures ANOVAs were conducted on the mean amplitude of each target-locked ERP and on the latency of the P3 with Task (single-task, dual-task), Previous interval (short, long) and Electrodes site (left, midline, right) as within-participants factors. Significant effects of Electrodes site were reported only if they interacted with Previous interval.

Results

Behavioural results. The overall accuracy (i.e., proportion of correct responses) across participants to the colour memory test was 0.74.

In the temporal orienting task, data from practice trials, the first trial of each block, trials involving premature responses (i.e., responses before target onset: 1.7%), trials with RTs below 150 ms (0.5%) and above 1000 ms (0.1%), and trials without responses (0.6%) were rejected from the analysis. A repeated-measures ANOVA was conducted on the RTs to respond to the target with Task (single-task, dual-task), Validity (valid, invalid), Previous interval (short, long) and Interval (short, long) as within-participants factors.

The main effect of Task was significant, $F(1, 15) = 6.64$, $p = .02$, $\eta p^2 = .3$, indicating that participants were slower in the dual-task condition as compared to the single-task condition. The main effect of Validity and the interaction between Validity and Interval also reached significance, $F(1, 15) = 14.72$, $p = .001$, $\eta p^2 = .4$, and $F(1, 15) = 14.44$, $p = .001$, $\eta p^2 = .4$, respectively. Importantly, validity effects were modulated by Task condition, as revealed by a significant Task x Validity interaction, $F(1,15) = 22.57$, $p < .001$, $\eta p^2 = .6$. Planned comparisons for this interaction showed that participants were faster on valid trials as compared to invalid trials in the single-task condition, $F(1,15) = 26.47$, $p<.001$, but not in the dual-task condition, $F<1$ (see Figure 13). This finding was also supported by a significant Task x Validity x Interval interaction, $F(1,15) = 32.64$, $p<.001$, $\eta p^2 = .6$, revealing that the interaction between Task and Validity was significant at the short interval, $F(1, 15) = 36.26$, $p < .001$, and marginally significant at the long interval, $F(1, 15) = 3.53$, $p = .07$. In particular, at the short interval validity effects were significant only in the single-task condition, $F(1, 15) = 39.76$, $p < .001$, but not in the dual-task condition, $F<1$. At the long interval, no validity effects were observed in either the single-task, $F(1, 15) = 1.40$, $p = .2$, or in the dual-task condition, $F(1, 15) = 1.45$, $p = .2$.

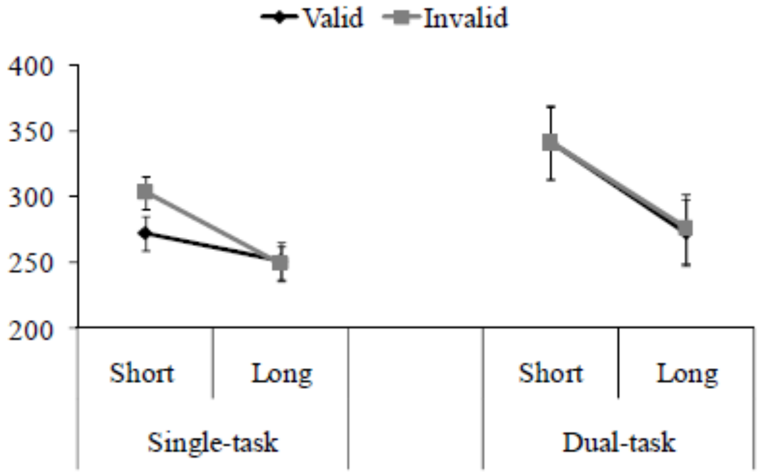


Figure 13. Mean reaction times (RTs) as a function of Task (single-task, dual-task), Validity (valid, invalid) and Interval (short, long). Vertical bars represent standard error of the mean.

The main effect of Previous interval was significant, *F*(1, 15) = 110.73 , *p* <.001, ηp^2 =.8, as participants responded faster after a previous short interval than after a previous long interval. The asymmetry of sequential effects was indexed by a significant Previous interval x Interval interaction, *F*(1,15) = 46.47, *p* <.001, ηp^2 =.7, with a larger effect of the previous interval at the current short interval than at the current long interval, although it reached statistical significance in both time intervals [*F*(1,15) = 84.42, *p* <.001, and *F*(1,15) = 16.58, *p* =.001, for the short and the long interval, respectively]. Crucially, sequential effects were not modulated by Task condition (see Figure 14), since the interactions involving Task and Previous interval factors were not statistically significant (*F*s <1 for both Task x Previous interval and Task x Previous interval x Interval interactions). Moreover, there were no significant interactions involving Validity and Previous interval (*p*s>.1 for both Validity x Previous interval and Validity x Previous interval x Interval interactions). Further a priori planned comparisons showed that validity effects were significant for both previous short and previous long intervals [*F*(1,15) = 8.14, *p* =.01, and *F*(1,15) = 5.16, *p* =.03, for the previous short and the previous long interval, respectively], as well as sequential effects were significant for both valid and invalid short-trials [*F*(1,15) = 63.69, *p*<.001, and *F*(1,15) = 33.23, *p*<.001, for the short-valid and the short-invalid trial, respectively].

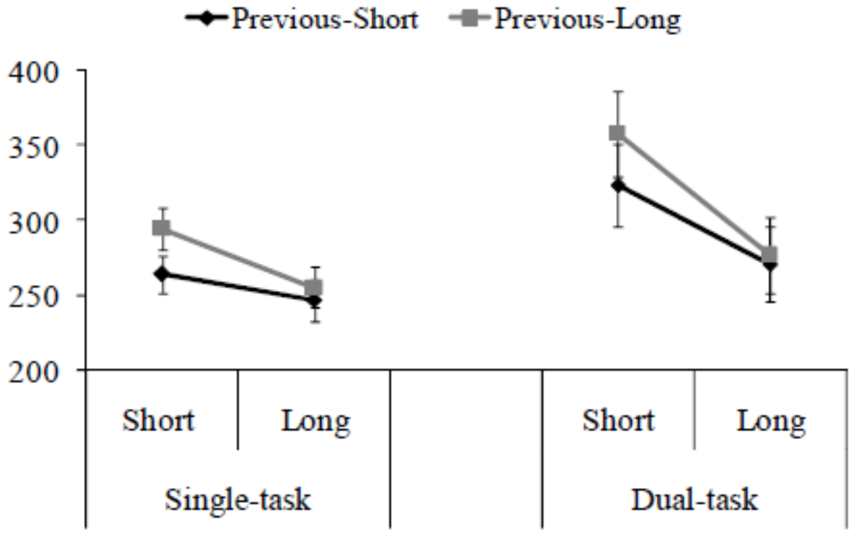


Figure 14. Mean reaction times (RTs) as a function of Task (single-task, dual-task), Previous interval (short, long) and Interval (short, long). Vertical bars represent standard error of the mean.

Finally, there was a significant main effect of Interval, *F*(1,15) = 124.95, *p*<.001, ηp^2 =.8, with participants responding faster at the long interval as compared to the short interval, and a significant Task x Interval interaction, *F*(1,15) = 20.01, *p*<.001, ηp^2 =.5, with a larger difference in participants' RTs between the single-task and the dual-task condition at the short interval as compared to the long interval [*F*(1,15) = 9.88, *p* =.006, and *F*(1,15) = 3.13, *p* =.09, for the short and the long interval, respectively].

Electrophysiological results.

Cue-locked ERPs. The CNV analysis revealed a significant main effect of Time bin, *F*(4,60)= 4.96, *p*=.01, ηp^2 =.2. Trend analyses showed that the time course of the CNV followed a significant linear trend, *F*(1,15)=7.19, *p*=.01 (i.e., it became more negative across the preparatory interval) rather than a quadratic trend, *F*<1. The main effect of Task was marginally significant, *F*(1,15)= 3.61, *p*=.07, ηp^2 =.1, revealing attenuated CNV amplitude (i.e., less negative) in the dual-task condition (-0.47 µv) as compared to the single-task condition (-0.82 µv). This Task effect was better qualified by a significant Task x Cue interaction, *F*(1,15)= 7.63, *p*=.01, ηp^2 =.3, showing that the CNV amplitude was more negative for early cue than for late cue in the single-task condition [-0.99 µv versus -0.65 µv, $F(1,15)= 12.79$, $p=.002$], but not in the dual-task condition [-0.45 µv versus -0.50 µv, $F<1$].

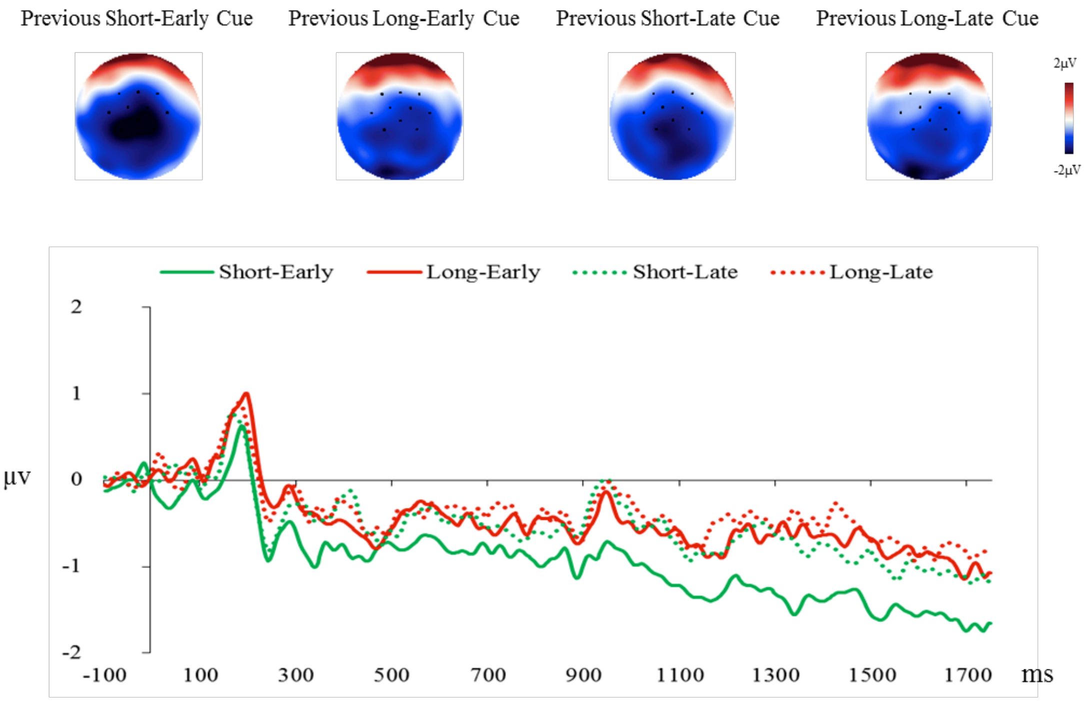
There was a significant main effect of Previous interval, $F(1,15)= 6.67$, $p=.02$, $\eta p^2 =.3$, with more negative CNV amplitude when the previous interval was short (-0.76 µv) as compared to when it was long (-0.53 µv). This effect interacted with Time bin, $F(4,60)= 4.75$, $p=.002$, $\eta p^2 =.2$. Bonferroni corrected comparisons ($\alpha=.01$) for this interaction showed that the effect of Previous interval was significant for each of the last two time bins [$F(1,15)= 9.21$, $p=.008$, and $F(1,15)= 8.97$, $p=.009$, respectively], while it was not significant for the first, $F(1,15)= 1.59$, $p=.2$, the second, $F(1,15)= 4.53$, $p=.05$, and the third time bin, $F(1,15)= 4.4$, $p=.05$.

The interaction between Task and Previous interval was marginally significant, $F(1,15)= 4.3$, $p=.055$, $\eta p^2 =.2$. Subsequent planned comparisons revealed that the CNV amplitude was more negative when the previous interval was short rather than long in the single-task condition [-1.02 µv versus -0.61 µv, $F(1,15)= 14.73$, $p=.001$], but not in the dual-task condition [-0.49 µv versus -0.45 µv, $F<1$].

In order to test whether our results replicated Los and Heslenfeld's (2005) study in the single-task condition, separate ANOVAs were conducted on each task condition over the final part of the CNV (i.e., at the last 200 ms before early target onset) with Cue, Previous interval and Electrodes site as factors. The ANOVA on the single-task condition showed significant main effects of both Cue, $F(1,15)= 9.27$, $p=.008$, $\eta p^2 =.3$, and Previous interval, $F(1,15)= 13.43$, $p=.002$, $\eta p^2 =.4$. Although the interaction between the two factors was not significant, $F(1,15)= 2.8$, $p=.1$, $\eta p^2 =.1$, further planned comparisons revealed that the effect of previous interval was significant only when the cue was early, $F(1,15)= 11.89$, $p=.003$, but not when it was late, $F(1,15)= 2.63$, $p=.1$ (see Figure 15). The ANOVA on the dual-task condition revealed no significant main effects or interactions (all ps>.5).

In sum, the analysis of cue-related activity revealed significant effects of cueing and previous interval, that seemed to interact, on the modulation of the CNV amplitude in the single-task condition. Both effects were eliminated in the dual-task condition.

A. Single-Task



B. Dual-Task

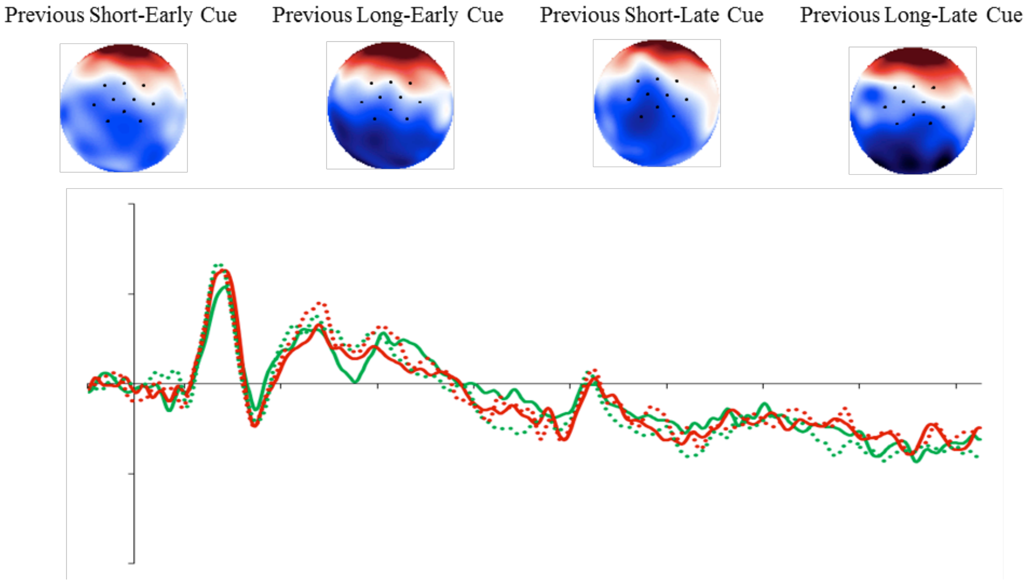


Figure 15. Grand average waveforms and topographies (with the corresponding electrodes used for the statistical analysis) of the CNV as a function of Cue (early, late) and Previous interval (short, long) for the single-task condition (A) and the dual-task condition (B).

Target-locked ERPs.

Temporal orienting. There were no significant main effects or interactions between Task and Validity for either P1 or N1 amplitudes (all ps>.16).

The ANOVA on the N2 amplitude revealed a significant main effect of Task, $F(1,15)= 15.22$, $p=.001$, $\eta p^2 =.5$, such that the amplitude of the N2 was larger in the dual-task condition (1.06 μv) as compared to the single-task condition (2.12 μv; see Figure 16). Importantly, validity effects were modulated by Task condition as revealed by a significant Task x Validity interaction, $F(1,15)= 7.83$, $p=.01$, $\eta p^2 =.3$. Planned comparisons for this interaction showed that the N2 was attenuated for valid trials as compared to invalid trials in the single-task condition [2.48 μv versus 1.76 μv, $F(1,15)= 8.9$, $p=.009$], but not in the dual-task condition [1.01 μv versus 1.11 μv, $F<1$]. There was also a significant Validity x Electrodes site interaction, $F(2,30)= 4.38$, $p=.02$, $\eta p^2 =.2$. This interaction was due to larger validity effects at the right site than at the othertwo sites, although Bonferroni corrected ($\alpha=.017$) comparisons showed that validity effects were not significant in any of the three sites [$F(1,15)= 1.16$, $p=.2$, for the left site, $F(1,15)= 2.84$, $p=.1$, for the midline site, and $F(1,15)= 5.66$, $p=.03$, for the right site]. None of the other terms in the ANOVA reached statistical significance (all $ps>.1$).

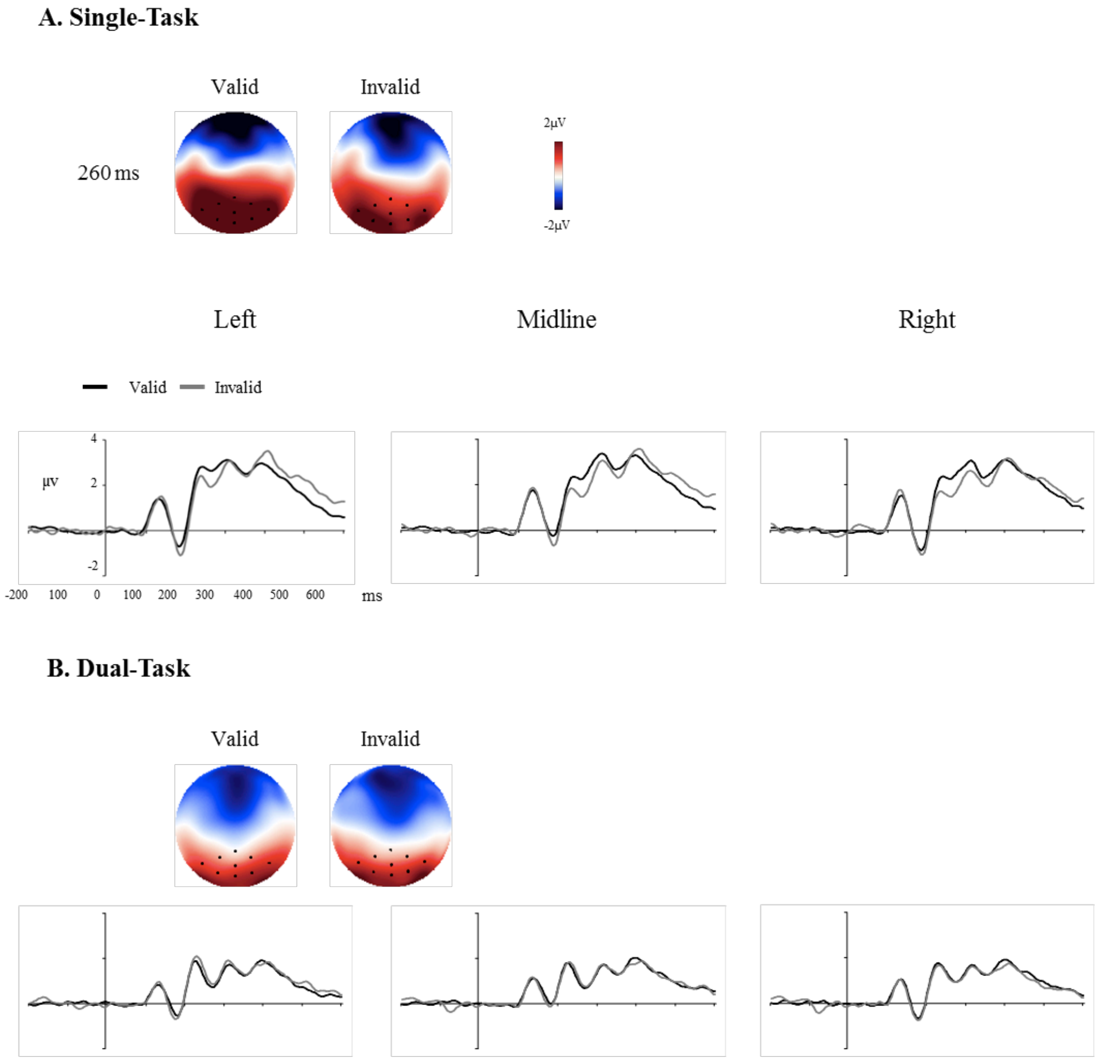


Figure 16. Grand average waveforms for the left, midline and right sites and topographies (with the corresponding electrodes used for the statistical analysis) of the N2 as a function of Validity (valid, invalid) for the single-task condition (A) and the dual-task condition (B).

The ANOVA on the P3 amplitude revealed a significant main effect of Task, *F*(1,15)= 12.83, *p* =.003, ηp^2 =.4, with a larger amplitude in the single-task condition (2.68 μv) as compared to the dual-task condition (1.67 μv). There was a significant Validity x Electrodes site interaction, *F*(2,30)= 9.51, *p* <.001, ηp^2 =.3. Bonferroni corrected comparisons (α=.017) for this interaction showed that validity effects were marginally significant for the right site, *F*(1,15)= 6.26, *p* =.02, but not for the left and the midline sites [*F*(1,15)= 1.01, *p*=.3, and *F*(1,15)= 2.15, *p*=.1, for the left and the midline site, respectively]. Although the Task x Validity interaction failed to reach statistical significance, *F*(1,15)= 1.60, *p* =.2, ηp^2 =.09, hypothesis-driven planned comparisons revealead that validity effects were marginally significant in the single-task condition, *F*(1,15)= 3.8, *p* =.07, but not significant in the dual-task condition, *F*<1.

The ANOVA on the P3 latency displayed only a significant Task x Validity x Electrodes site interaction, *F*(2,30)= 4.44, *p*=.02, ηp^2 =.2 (*p*s>.22 for all the other main effects and interactions). Separate ANOVAs for each electrode site showed that the Task x Validity interaction was only significant for the left site, *F*(1,15)= 5.01, *p*=.04, ηp^2 =.2, but not for the midline and the right sites [*F*<1 for both sites]. Specifically, for the left site the P3 following a valid trial peaked earlier as compared to the P3 following an invalid trial in the single-task condition [387 ms versus 399 ms, F(1,15)= 14.96, p=.001] as compared to the dual-task condition [396 ms versus 394 ms, F<1; see Figure 17] 3. There were no significant validity effects in either the single-task or the dual-task condition for the midline and the right sites (all *p*s>.1).

To sum up, activity related to temporally expected targets, with respect to unexpected targets, attenuated the N2 amplitude and reduced the P3 latency only in the single-task condition. In contrast, temporal orienting of attention did not result in any effect on target processing at the P1 and N1 potentials in either the single-task or the dual-task condition.

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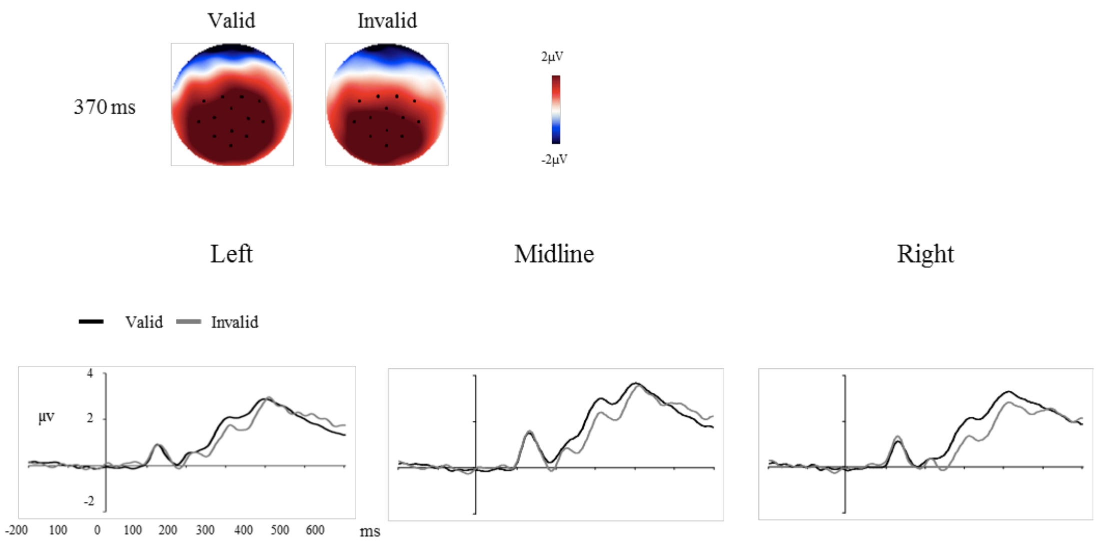
[3] As can be observed in Figure 6, the P3 was preceded by another positive deflection ($P3_1$) peaking at around 280-340 ms. Separate repeated-measures ANOVAs were conducted on the mean amplitude and latency of this ERP with Task (single-task, dual-task), Validity (valid, invalid) and Electrodes site (left, midline, right) as factors. The ANOVA on the $P3_1$ amplitude elicited a significant main effect of Task, *F*(1,15)= 24.91, *p* <.001, ηp^2 =.6, indicating that the $P3_1$ amplitude was smaller in the dual-task condition (0.73 μv) than in the single-task condition (1.93 μv). Validity effects were modulated by Task condition, as indexed by a significant Task x Validity interaction, *F*(1,15)= 5.15, *p* =.03,ηp^2 =.2, with validity effects being significant in the single-task condition, *F*(1,15)= 6.18, *p* =.02, but not in the dual-task condition, *F*<1. The main effect of Validity was only marginally significant, *F*(1,15)= 3.83, *p* =.06, ηp^2 =.2, and interacted with Electrodes site, *F*(2,30)= 4.52, *p* =.01, ηp^2 =.2. Planned comparisons for this interaction showed that validity effects were marginally significant for the right site, *F*(1,15)= 5.85, *p*=.02 (Bonferroni corrected, α=.017), but not for the left and the midline sites [*F*(1,15)= 2.14, *p*=.1, and *F*(1,15)= 3.22, *p*=.09, for the left and the midline site, respectively]. The ANOVA on the $P3_1$ latency did not reveal any significant main effects or interactions (all *ps*>.065).

A. Single-Task



B. Dual-Task

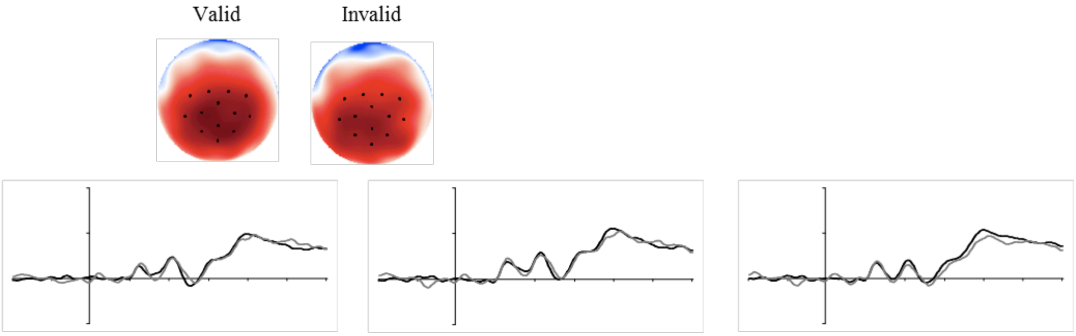
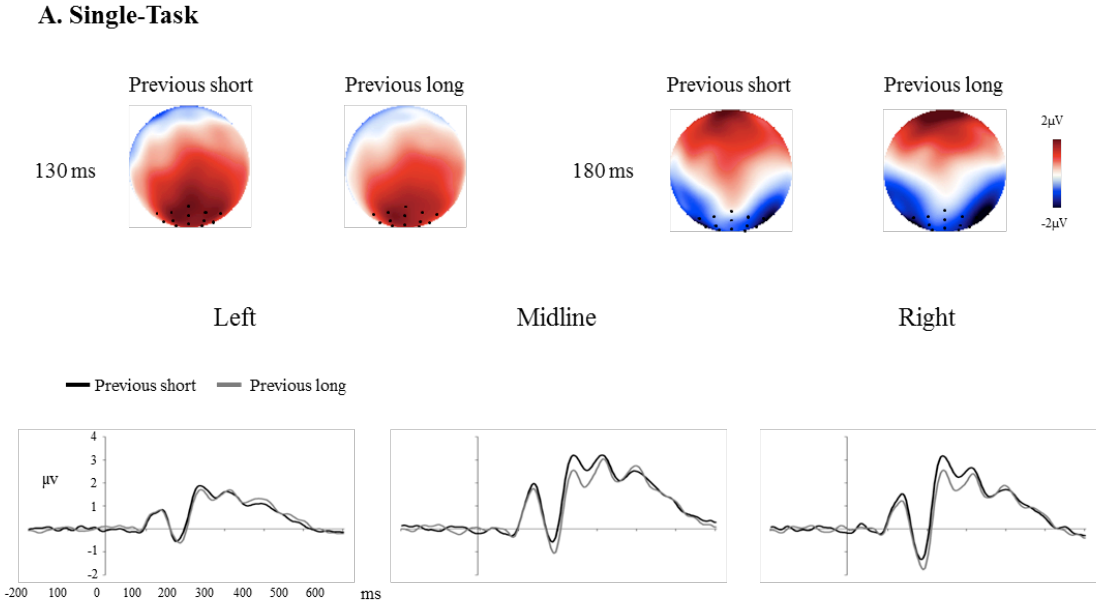


Figure 17. Grand average waveforms for the left, midline and right sites and topographies (with the corresponding electrodes used for the statistical analysis) of the P3 as a function of Validity (valid, invalid) for the single-task condition (A) and the dual-task condition (B).

Sequential effects. The ANOVA on the P1 amplitude showed a significant Previous interval x Electrodes site interaction, $F(2,30)= 3.68$, $p=.03$, $\eta p^2 =.1$. Bonferroni corrected ($\alpha=.017$) comparisons for this interaction showed that the P1 amplitude was larger when the previous interval was short as compared to when it was long in the right site [1.24 µv versus 0.96 µv, $F(1,15)= 7.56$, $p=.015$], while it did not reach statistical significance in either the left [0.98 µv versus 0.89 µv, $F<1$] or the midline site [1.41 µv versus 1.24 µv, $F(1,15)= 2.01$, $p=.1$]. The main effect of Previous interval was not modulated by Task condition since both the Task x Previous interval and the Task x

Previous interval x Electrodes site interaction were not significant (both *F*s <1; see Figure 18).

The ANOVA on the N1 amplitude showed a significant Task x Previous interval interaction, *F*(1,15)= 6.75, *p*=.02, ηp^2 =.3, such that the N1 was attenuated when the previous interval was short than when it was long in the single-task condition [-0.61 µv versus -0.94 µv *F*(1,15)= 3.52, *p*=.07] as compared to the dual-tak condition [-0.39 µv versus -0.31 µv, *F*<1; see Figure 7]. None of the remaining terms of the ANOVA reached statistical significance (all *p*s>. 13).


A. Single-Task

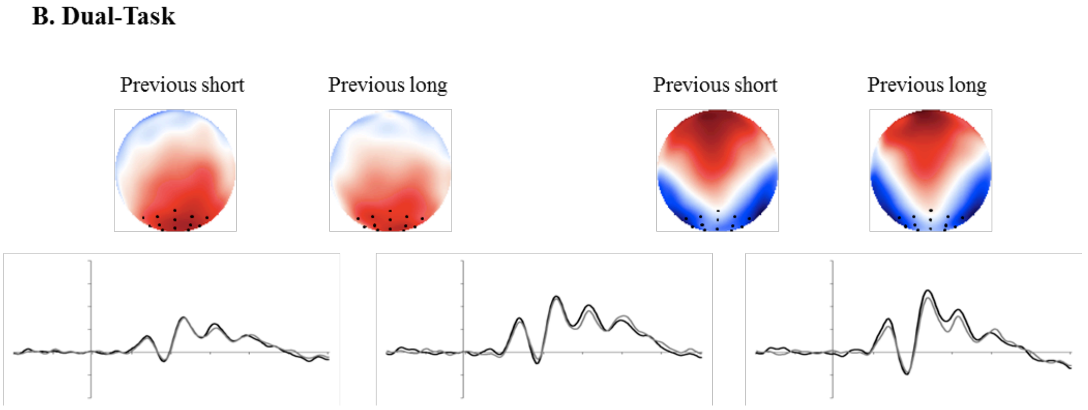

B. Dual-Task

Figure 18. Grand average waveforms for the left, midline and right sites and topographies (with the corresponding electrodes used for the statistical analysis) of the P1 and N1 as a function of Previous interval (short, long) for the single-task condition (A) and the dual-task condition (B).

The ANOVA on the N2 amplitude showed a significant main effect of Task, *F*(1,15)= 20.44, *p*<.001, ηp^2 =.5, such that the amplitude of the N2 was larger in the dual-task condition (1.02 µv) as compared to the single-task condition (2.30 µv; see Figure 19). The main effect of Previous interval was significant, *F*(1,15)= 21.83, *p*<.001, ηp^2 =.5, such that the N2 amplitude was attenuated when the previous interval was short (1.89 µv) rather than long (1.43 µv). The effect of Previous interval interacted with Task condition as revealed by a significant Task x Previous interval interaction, *F*(1,15)= 10.86, *p*=.004, ηp^2 =.4. Planned comparisons for this interaction showed that the N2 was attenuated when the previous interval was short as compared to when it was long in the single-task condition [2.69 µv versus 1.91 µv, *F*(1,15)= 38.81, *p*<.001], but not in the dual-task condition [1.08 µv versus 0.95, *F*<1]. There was also a Previous interval x Electrodes site interaction, *F*(2,30)= 9.71, *p*<.001, ηp^2 =.3. This interaction was explained by a larger difference between previous short and previous long intervals in the right and midline sites [*F*(1,15)= 43.9, *p*<.001, for the right site, and *F*(1,15)= 22.74, *p*<.001, for the midline site], as compared to the left site, *F*(1,15)= 4.95, *p*=.04 (Bonferroni corrected, α=.017).

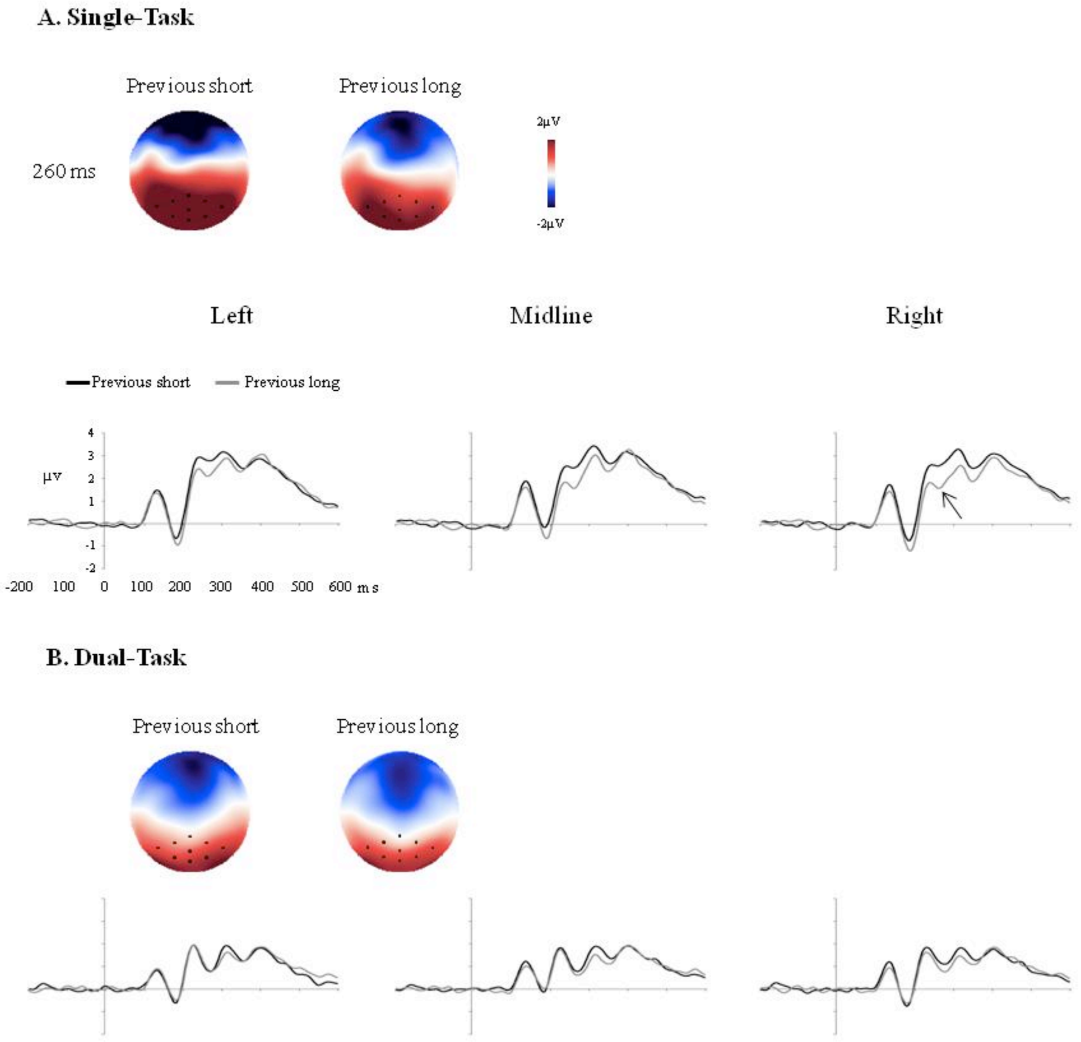


Figure 19. Grand average waveforms for the left, midline and right sites and topographies (with the corresponding electrodes used for the statistical analysis) of the N2 as a function of Previous interval (short, long) for the single-task condition (A) and the dual-task condition (B).

The ANOVA on the P3 amplitude elicited a significant main effect of Task, *F*(1,15)= 13.82, *p* =.002, ηp^2 =.4, indicating that the P3 amplitude was smaller in the dual-task condition (1.70 µv) than in the single-task condition (2.74 µv). The effect of Previous interval was significant, *F*(1,15)= 9.71, *p* =.007, ηp^2 =.3, with larger P3 amplitude when the previous interval was short (2.40 µv) than long (2.05 µv). Although the Task x Previous interval interaction failed to reach statistical significance (*F*<1), hypothesis-driven planned comparisons revealead that the effect of previous interval was significant in the single-task condition, *F*(1,15)= 9.45, *p* =.007, and marginally significant in the dual-task condition, *F*(1,15)= 3.95, *p* =.06 (see Figure 20).

The ANOVA on the P3 latency displayed only a significant Task x Previous interval x Electrodes site interaction, *F*(2,30)= 6.24, *p*=.005, ηp^2 =.2 (*p*s>.4 for all the other main effects and interactions). Separate ANOVAs for each site showed that the Task x Previous interval interaction was marginally significant for the right site, *F*(1,15)= 3.98, *p*=.06, ηp^2 =.2, but not for the left and the midline sites (*ps*>.1 for both sites). Specifically, on the right site the difference between previous short (396 ms) and previous long interval (403) was larger in the single-task condition as compared to the dual-task condition (399 ms versus 397ms), although such a difference did not approach statistical significance in either task condition [*F*(1,15)= 2.01, *p*=.1 and *F*<1, for the single-task and the dual-task condition, respectively] [4].

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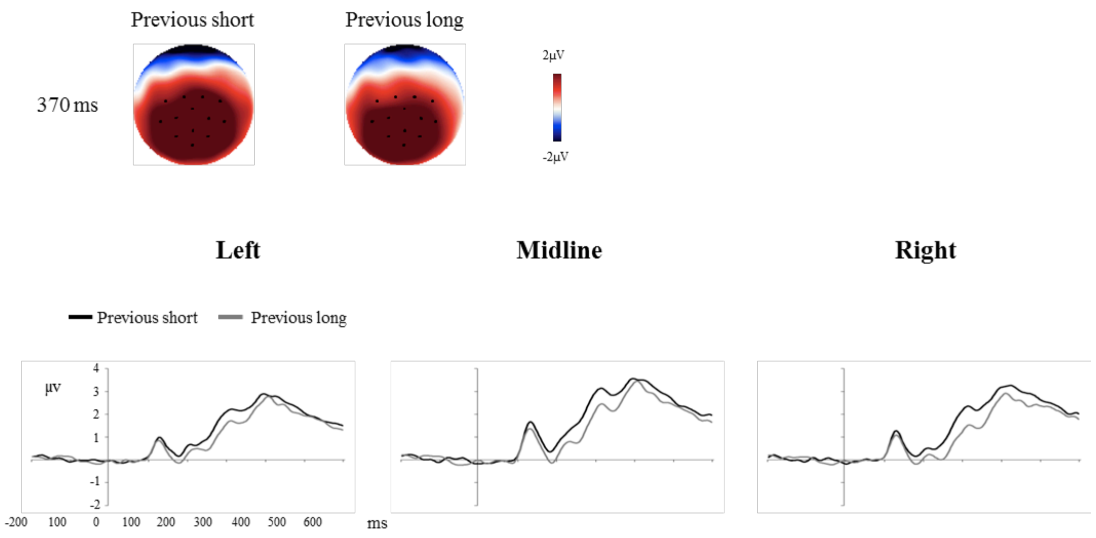
[4] Similarly to temporal orienting, separate ANOVAs were conducted on the mean amplitude and latency of the $P3_1$ potential (see Figure 9) with Task (single-task, dual-task), Previous interval (short, long) and Electrodes site (left, midline, right) as factors. Analysis on the $P3_1$ amplitude elicited a significant main effect of Task, F(1,15)= 25.98, p <.001, ηp^2 =.6, indicating that the $P3_1$ amplitude was smaller in the dual-task condition (0.75 µv) than in the single-task condition (2.04 µv). The effect of Previous interval was significant, F(1,15)= 17.65, p <.001,ηp^2 =.5, with larger $P3_1$ amplitude when the previous interval was short (1.67 µv) than long (1.12 µv). There was a significant Previous interval x Electrodes site interaction, F(2,30)= 3.43, p=.04, ηp^2 =.1. Bonferroni corrected (α=.017) comparisons for this interaction revealed a larger difference between previous short and previous long intervals in the right site than in the other two sites, although the effect reached statistical significance in the three sites [F(1,15)= 21.37, p<.001, for the right site, F(1,15)= 13.97, p=.001, for the left site, and F(1,15)= 14.68, p=.001, for the midline site]. The interactions involving Task condition did not approach significance (all ps>.1). The ANOVA on the $P3_1$ latency displayed only a marginal significant effect of Task, F(1,15)= 3.35, p =.08, ηp^2 =.1.

A. Single-Task



B. Dual-Task

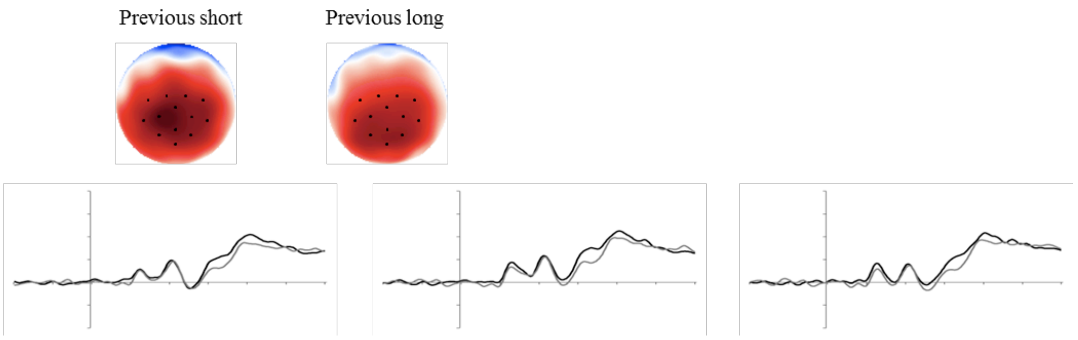


Figure 20. Grand average waveforms for the left, midline and right sites and topographies (with the corresponding electrodes used for the statistical analysis) of the P3 as a function of Previous interval (short, long) for the single-task condition (A) and the dual-task condition (B).

To sum up, target-related activity revealed sequential effects at the P1 and N1 potentials. The P1 amplitude was larger when the previous interval was short than when it was long over the right site in both the single-task and the dual-task condition. Conversely, the N1 and N2 potentials were attenuated following a previous short interval as compared to a previus long interval only in the single-task, but not in the dual-task condition. The amplitude of the P3 potential was larger when the previous interval was short versus long in both task conditions. In contrast, the latency of the P3 was modulated by dual-task demands.

Discussion

In the present study, we explored the locus of interference between temporal preparation and working memory tasks by using a dual-task paradigm. Participants simply performed the temporal orienting task in the single-task session and in conjunction with a working memory updating task in the dual-task session. On the basis of prior findings (Capizzi et al., 2012), it was predicted that temporal orienting effects would be only obtained in single-task relative to dual-task conditions, while sequential effects would not be reduced by extra processing demands.

The behavioural results confirmed that the concurrent updating of colour information in working memory impaired participants' ability to voluntarily orient attention in time. The ERP results further corroborated the involvement of controlled processing in temporal orienting of attention by showing that working memory manipulation interfered in a selective way with neural activity linked to validity effects, as indexed by both preparatory CNV and late target-locked N2 and P3 potentials (cf., Nobre, 2001).

With respect to sequential effects, the behavioural data confirmed their resistance to working memory interference, as they were not reduced by concurrent dual-task demands. Interestingly, however, the behavioural dissociation between temporal orienting and sequential effects was supported only partially by the ERP findings. On the one hand, as expected on the basis of Los and Heslenfeld's (2005) results, there was a significant effect of previous interval on the modulation of the CNV in addition to that of temporal orienting. On the other hand, however, both effects were eliminated by dual-task demands. Target-related activity also revealed some differences (at P1 and N1) as well as some similarities (at N2 and P3) between temporal orienting and sequential effects, which suggested a certain degree of neural overlap in the modulation of target processing at post-perceptual stages.

The interference between temporal orienting of attention and working memory tasks occurred at preparatory stages preceding the onset of the target. The effect of predictive temporal cues on preparatory processes has been reliably associated to the modulation of the amplitude of the CNV. Early cues lead to higher modulation of the CNV (i.e., more negative) before the moment of early target onset as compared to late cues (Los & Heslenfeld, 2005; Miniussi et al., 1999), which shows that preparatory processes are initiated by cue-based information in order to increase response readiness to the upcoming event. It has been recently reported (Zanto et al., 2011) that in contrast to younger adults, older adults revealed neither behavioural benefits from temporal cues nor CNV preparatory activity, suggesting an age-related failure to form temporal expectancies about the subsequent target stimulus. Our data add to these observations, indicating that the concurrent performance of a demanding working memory task may also interfere with the development of anticipatory processes related to temporal orienting, as reflected in the reduction of the CNV amplitude under dual-task relative to single-task conditions.

This finding shares some similarities with a recent EEG experiment (Gontier et al., 2007), which reported that task interference deteriorated performance and decreased amplitudes of CNV and P3 potentials in an explicit timing task requiring participants to discriminate between two durations. The fact that both explicit (Gontier et al., 2007) and implicit (our experiment; see Coull and Nobre, 2008) timing tasks behaved similarly under augmented cognitive load is in agreement with the idea that the two tasks are supported by a common timing mechanism (see Piras & Coull, 2011, for similar conclusions). Along the same line, Triviño et al. (2011) recently showed that right frontal patients displayed a severe deficit in both time estimation (i.e., overestimation in the range of milliseconds and minutes) and temporal orienting tasks. Future research should test further the role of time perception in temporal preparation tasks, for example, by comparing explicit and implicit timing tasks under similar extra processing demands.

The CNV results replicated only partially the findings by Los and Heslenfeld (2005), as the CNV amplitude was more negative before the moment of early target onset when the previous interval was short rather than long. However, such an effect was reported only when the cue was directing attention to the early moment but not to the late moment. The difference between Los and Heslenfeld’s (2005) study and the present findings suggests that there could be also interactive modulation of temporal orienting and sequential effects on the development of temporal preparation. In any case, one would expect that the CNV component associated to sequential effects should be resistant to working memory interference. Surprisingly, however, both temporal orienting and sequential effects on the CNV were eliminated by the working memory task. This result is difficult to explain from Los and colleagues' model (Los, 1996; Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001) stating that sequential effects would reflect the operation of a single automatic mechanism since, if this were the case, there should not be any change of sequential effects over the CNV under dual-task conditions.

Otherwise, it might be possible that the disruption of sequential effects by dual-task interference was due to the fact that such effects, albeit automatic, could be modulated by endogenous factors (e.g., Ruz & Lupiañez, 2002; Fodor, 1983). In the field of temporal preparation, previous studies have already implied that sequential effects may be contingent on a particular attentional set. For example, Los and Van den Heuvel (2001) showed that sequential effects were larger when attention was not explicitly directed to a particular moment in time, that is, on invalid temporal orienting conditions, which suggested that endogenous strategic processes could modulate the magnitude of sequential effects. In a similar vein, it has been reported that sequential effects differed between high trait impulsivity as compared to low trait impulsivity groups (i.e., sequential effects facilitated response inhibition selectively in the low impulsivity group: Correa, Triviño, Pérez-Dueña, Acosta, & Lupiañez, 2010). As impulsivity is an index of attentional control (e.g., Rubia et al., 2003), Correa et al.'s (2010) results also suggest that sequential effects may be influenced by controlled factors. Lastly, sequential effects are larger in the context of a blocked-manipulation of temporal cues as compared to a within-trials design (Correa et al., 2004). Once again, since generating a new temporal expectancy on each trial is more demanding than generating a single temporal expectancy for a whole block, such findings suggest that the expression of sequential effects may be influenced in the context of controlled task sets.

But, if we assume that increased attention control in the dual-task condition might have affected the expression of sequential effects on the CNV potential, then the following question is in order: which are the electrophysiological correlates of sequential effects that contributed to the behavioural dual-task benefit? The analysis of target related activity was particularly important to answer to this question and elucidate the mechanisms underlying the behavioural dissociation between temporal orienting and sequential effects.

In relation to temporal orienting effects, the results of target-locked ERPs closely paralleled the behavioural data in agreement with prior literature. Consistent with our predictions, we found the typical modulation of the N2 amplitude and P3 latency when participants were only engaged in the single-task condition (Correa et al. 2006; Doherty et al. 2005; Griffin et al. 2002), but not when they performed the working memory task concurrently with the temporal orienting task. Attenuation of the N2 by temporal expectancy has been reported as a common hallmark in temporal orienting research (see Correa et al., 2006, for a review). The functional processes underlying this modulation may be related to the fact that temporally anticipated targets benefit from a more efficient releasing of inhibitory control mechanisms that would be in charge of "prevent responding at inappropriate times" (cf. Correa & Nobre, 2008; see also Davranche et al., 2007). This explanation fits in well with lesion studies proposing a key role of the prefrontal cortex in inhibitory control during temporal preparation (Triviño et al., 2011; 2010; Vallesi et al., 2007; Narayanan et al. 2006). Our data showed that when attention was withdrawn from the temporal orienting task by focusing on concurrent working memory demands, there was no modulation of the N2 amplitude by temporal expectancy, suggesting a failure of temporal preparation to release inhibitory control under dual-task conditions.

The reduction of the P3 latency by temporal expectancy also replicated previous findings (Correa & Nobre, 2008; Doherty et al., 2005; Griffin et al. 2002; Miniussi et al., 1999), indicating that preparing on the basis of predictive temporal information speeds up late potentials related to target onset. Interestingly, the P3 latency modulation was abolished when the working memory task was introduced, indexing a competition for resources between the two tasks being performed at critical late stages of information processing, which is in line with the idea that temporal orienting mainly modulates post-perceptual components (Nobre, 2001).

Regarding sequential effects, analysis of target-related activity showed an early effect by the duration of the previous trial on the P1 potential. The P1 amplitude increased when the previous interval was short rather than long under both the single-task and the dual-task condition. At first glance, this finding may seem counterintuitive since beneficial consequences of sequential effects on perceptual processing do not fit with the idea of their late motor locus (e.g., Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001). As discussed above, motor-related ERP potentials, like the CNV, are sensitive to the duration of the previous trial. In addition to the CNV, Van der Lubbe et al. (2004) measured the lateralized readiness potential (LRP) as an index of motor preparation. The LRP is a waveform obtained by the difference between the EEG activity recorded above the primary motor areas contra- and ipsi-lateral to the response hand (Coles, 1989). Its amplitude mainly reflects the motor activation of the responding hand. Van der Lubbe et al.'s (2004) reults showed that the LRP amplitude was larger when the previous interval was short as compared to when it was long, suggesting that sequential effects influenced motor processes related to anticipation of the upcoming stimulus. However, since both Los and Heslenfeld's (2005) and Van Der Lubbe at al.'s (2004) studies did not consider target-related activity, the question of whether sequential effects would also involve different types of target modulation at perceptual or central stages of processing remained unanswered.

It is difficult to pinpoint the functional significance of the early modulation by sequential effects shown here as, to the best of our knowledge, it represents a novel finding. Moreover, one might argue that our P1 results were influenced by overlapping activity from preceding events (see Woldorff, 1993). We were reassured that this was not the case since, on the one hand, a strict baseline correction was applied to the target analysis and, on the other hand, such an early effect should also be observed for temporal orienting, if it had been driven exclusively by activity from previous events.

A possible explanation considers that the P1 modulation could reflect some automatic processing of sensory information triggered by the participant's state of arousal. According to the dual-process model (Vallesi, 2010), repetition of a previous short interval would increase arousal levels as compared to alternation from a previous long interval. Other researchers (e.g., Vogel & Luck, 2000) have found a larger P1 amplitude for high levels versus low levels of arousal, thus supporting our claim The fact that this early effect resisted to dual-task interference could also be taken as further demonstration that the arousal process is a key component of sequential effects. Future studies are needed to corroborate these suggestions and to better clarify the functional meaning of this early P1 effect.

The second ERP deflection that was sensitive to the duration of the previous trial was the N1 potential. Less negativity was elicited by repetition of a previous short interval as compared to alternation from a previous long interval in the single-task condition, while this effect was absent in the dual-task condition. A reduced N1 amplitude for repetition of a short interval could be related to repetition-suppression effects, as neural activation for repeating trials (previous short interval) would be reduced as compared to alternating trials (previous long interval; see Grill-Spector et al., 2006, for a review).

Taken together, the results from the P1 and N1 potentials for sequential effects diverged from the findings on temporal orienting that revealed no modulation of early processing stages by valid trials as compared to invalid trials. In contrast, a similar pattern for both temporal orienting and sequential effects was observed for the N2 and P3 potentials. The N2 was attenuated by a previous short interval as compared to a previous long interval in the single-task condition, while this modulation was absent in the dual-task condition. This finding could suggest a possible role for inhibition in the expression of sequential effects that would be similar to the functional meaning of the N2 for temporal orienting. According to Los (2010), inhibition could be indeed involved in sequential effects as it would be implemented during intertrial transitions to prevent participants from making a premature response.

However, the high similarity between the modulation of the N2 for both temporal orienting and sequential effects (see Figures 5 and 8) makes us cautious before drawing strong conclusions on the meaning of the N2 for sequential effects. As already pointed out above, it is likely that a controlled task set might have influenced the expression of sequential effects. This explanation is supported by the fact that the modulation of the N2 amplitude was disrupted by dual-task demands in a similar way for both temporal orienting and sequential effects. To control for this possibility, future research should include a neutral condition in which the predictive temporal cue should be replaced by a non-informative warning signal. If the N2 modulation by sequential effects would be replicated outside the context of a temporal orienting (endogenous) procedure, then it could be concluded that it truly reflected activity linked to the duration of the previous interval.

The last similarity between the two temporal preparation effects was observed at the P3 potential. A larger P3 amplitude was found for previous short as compared to previous long intervals, as well as for valid as compared to invalid trials. These findings suggest that, in addition to temporal orienting, sequential effects could also facilitate the synchronization and preparation of fast responses to target onsets. The fact that such a facilitation by sequential effects survived to dual-task interference supports this argument. However, a puzzling aspect of these data is that the P3 latency was affected by dual-task demands for both temporal orienting and sequential effects, suggesting again a possible influence of controlled factors.

To conclude, the present ERP findings provided novel electrophysiological evidence of interference between performance of a concurrent working memory task and both temporal orienting and sequential effects at late processing stages. This result suggests that although the two temporal effects can be behaviourally dissociated in the context of a dual-task paradigm, they can be influenced in a similar way by simultaneous task demands. Such a pattern of data does not cast doubt on the automaticity of sequential effects, but it opens the possibility that they can be higly sensitive to modulation by controlled factors. The next research step would be to employ a neutral control condition to better isolate the pure modulation of sequential effects on target processing. On the contrary, the present ERP findings strengthened the involvement of controlled processing in the ability to voluntarily orient attention in time, by showing a selective dual-task interference with processing stages typically linked to temporal orienting of attention.

Chapter VI: Electrophysiological correlates of temporal sequential effects

The content of this chapter is in preparation as Capizzi, M., Sanabria, D, Correa, A., Rochet, N., & Burle, B. (in preparation). Electrophysiological correlates of temporal sequential effects.

Abstract

The main goal of the present study was to investigate the electrophysiological correlates of temporal sequential effects in the context of a variable foreperiod design. Sequential effects refer to the finding of faster responses at current short foreperiods when current and previous foreperiod match in duration (i.e., short-short sequence) than when they mismatch (long-short sequence). By contrast, on current long trials, participants' responses are equally fast for both repeating and alternating foreperiods (long-long sequence versus short-long sequence). Previous studies have related sequential effects to motor arousal or conditioning mechanisms operating on previous trials. Together with effects at the P3 potential, we report evidence that sequential effects may also optimize behaviour by enhancing early perceptual processing stages as indexed by the P1 potential.

Introduction

In recent years, increasing evidence has been accumulated showing that participants' responses to temporally expected stimuli are faster and more accurate than responses to temporally unexpected stimuli (Correa, 2010; Nobre, Correa, & Coull, 2007). A heightened state of temporal preparation may be achieved by either controlled or automatic mechanisms. The former would rely on explicit expectancies as to when a relevant event is going to occur (i.e., "temporal orienting of attention"; Nobre, 2001; Coull & Nobre, 1998). The latter would be determined by the preparatory state developed on the previous trial (i.e., "sequential effects"; Drazin, 1961; Los & Van den Heuvel, 2001; Steinborn, Rolke, Bratzke, & Ulrich, 2008; Vallesi & Shallice, 2007; Woodrow, 1914). The present work addressed the automatic aspect of temporal preparation. Specifically, we aimed at exploring the electrophysiological correlates of sequential effects by means of event-related potentials (ERPs).

In reaction time (RT) tasks in which the foreperiod (i.e., preparatory interval between a warning signal and a target stimulus) varies randomly from trial to trial (i.e., variable foreperiod paradigm), sequential effects are indexed by an interaction between preceding and current foreperiod duration. Participants' RT on current short trials is typically faster after repetition of a previous short as compared to alternation from a previous long foreperiod. Such RT pattern is usually restricted to current short trials, since on current long trials participants' responses are fast independently of whether the previous foreperiod was short or long. For that reason, sequential effects are referred to as "asymmetric".

An additional phenomenon that occurs in the variable foreperiod paradigm is the "foreperiod effect", which consists of faster RT at the current long as compared to the current short foreperiod (see Coull, 2009; Niemi & Näätänen, 1981, for reviews). Most of the previous work on the foreperiod effect has stressed a strategic account of temporal preparation (e.g. Alegria, 1975; Gottsdanker, 1975; Karlin, 1959). In a variable foreperiod paradigm, provided that short and long foreperiods have an equal a priori probability to occur in a trial, the conditional probability of target onset grows with the passage of time, so that participants may infer that the target has to appear at the longest foreperiod given that it has not yet occurred at the shortest one (Elithorn & Lawrence, 1955).

On this strategic account, it was originally proposed that sequential effects would also depend on internal volitional expectancies (e.g., Requin, Brener, & Ring, 1991; Niemi & Näätänen, 1981). That is, at the start of each trial participants would expect a repetition of the previous foreperiod rather than an alternation. Accordingly, the peak of preparation would be higher for a short-short foreperiod sequence but lower for a long-short sequence where the target occurs earlier than expected. By contrast, if the target occurs later than expected, that is, at the current long foreperiod, participants would re-prepare for a long foreperiod in due time thereby counteracting the negative effect on RT of an incorrect expectancy (e.g., Karlin, 1959; see Loveless & Sandford, 1974, for physiological evidence). However, this guessing strategy has been challenged by studies showing that, in sequences with two equiprobable alternatives, participants are more prone to expect an alternation rather than a repetition of the alternatives (e.g., the gambler's fallacy; Soetens, Boer, & Hueting, 1985 cited in Vallesi et al., 2007). Moreover, other studies have pointed out that sequential effects would be mediated by automatic, instead of controlled, mechanisms resistant to dual-task interference (Capizzi, Sanabria, & Correa, 2012) and relying on more primitive brain areas that develop earlier as compared to slow maturing frontal structures (Vallesi & Shallice, 2007).

In contrast to the strategic view, Los' "trace-conditioning" model (Los, 1996; Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001) proposed that sequential effects would result from an associative learning process based on automatic trace-conditioning between warning signal (i.e., the conditioned stimulus) and target onset (i.e., the unconditioned stimulus). Central to this model is the idea that a single automatic mechanism may account for both foreperiod and sequential effects, since participants' RT on the current trial would be inevitably influenced by the conditioning mechanisms operating on the previous trial. However, to the extent that a severe impairment of the foreperiod effect has been reported despite the presence of normal sequential effects, a single-process view cannot explain both temporal phenomena (see Triviño, Correa, Arnedo, & Lupiáñez, 2010; Vallesi, Mussoni et al., 2007, for neuropsychological evidence; Vallesi, Shallice, & Walsh, 2007, for a transcranial magnetic stimulation study).

A hybrid "dual-process" model combining automatic and controlled processing was put forward by Vallesi and coworkers to account for sequential effects (Vallesi, 2010; Vallesi & Shallice, 2007; Vallesi, Shallice, & Walsh, 2007). The key feature of this model is the automatic arousal effect (i.e., readiness to respond) from the previous trial. A previous short foreperiod would speed up RT since the participant's level of arousal would be higher. Conversely, a previous long foreperiod would lengthen RT as arousal levels would be lowered by the fact that maintaining an optimal state of preparation for a long period of time is energy consuming (e.g., Gottsdanker, 1975; Naatanen, 1972). The automatic arousal effect from the previous trial would operate regardless of the duration of the current foreperiod. However, on a current long foreperiod, this arousal effect would be attenuated by the controlled time-monitoring process checking the conditional probability of target occurrence over time (i.e., if the target has not yet occurred at the short foreperiod, it has to occur with full probability at the long foreperiod). For that, automatic processing would explain the benefit observed in short-short foreperiod sequences as compared to long-short sequences, while controlled processing would account for the asymmetry of sequential effects.

Other studies in the field of temporal preparation have implied that, albeit automatic in nature, sequential effects may be contingent on a particular attentional set. For example, Los and Van den Heuvel (2001) showed that, in the context of a temporal orienting procedure, in which participants are explicitly cued to orient their attention to a particular moment in time, sequential effects were reduced in valid conditions, while they were stronger in invalid conditions, that is, when the focus of attention was diverted away by an invalid prediction.

Support for the idea that sequential effects could be susceptible of modulation by controlled factors comes also from recent electrophysiological evidence. In a previous ERP study (Capizzi, Correa, & Sanabria, 2012), we adopted a dual-task paradigm to dissociate between automatic (sequential effects) and controlled (temporal orienting) contributions to temporal preparation. Participants simply performed the temporal orienting task in the single-task session and in conjunction with a working memory updating task in the dual-task session. Electroencephalography (EEG) was recorded during both task conditions to investigate the locus of interference between temporal preparation and working memory tasks. The results of this study showed that sequential effects differed from temporal orienting only at early visual processing stages (as indexed by the target-locked P1 and N1 potentials), while a strong neural overlap between the two temporal effects occurred at those late stages that have been systematically linked to temporal orienting of attention (at the N2 and P3; e.g., Nobre, 2001). Specifically, the N2 was attenuated and the P3 latency was shortened by valid versus invalid trials as much as by previous short versus previous long trials only in the single-task but not in the dual-task condition. These findings led to ask whether the modulation of target processing by sequential effects observed in Capizzi et al. (2012a) could have been influenced in the context of an endogenous temporal orienting procedure like in Los and Van den Heuvel' s (2001) behavioural study. That is, if sequential effects were contingent on top-down expectancies, triggered by the explicit temporal cue, then this might have resulted in some neural overlap between temporal orienting and sequential effects upon target processing. If so, the electrophysiological correlates of "pure" sequential effects were not determined conclusively in Capizzi et al.'s (2012a) work. Moreover, it is worth noting that, to the best of our knowledge, only another ERP study has so far investigated sequential effects in the context of a temporal orienting procedure (Los & Heslenfeld, 2005). Unfortunately, however, Los and Heslenfeld did not take target processing into account since they only explored preparatory activity preceding the onset of the target, as indexed by the contingent negative variation (CNV) and the lateralized readiness potential (LRP).

Here, we investigated the modulation of sequential effects on target processing by means of a variable foreperiod paradigm, in which participants were not explicitly required to predict the occurrence of the forthcoming target. The substitution of a predictive temporal cue, as that used in Capizzi et al. (2012a), for a neutral warning signal aimed at reducing the influence of controlled factors at the current short foreperiod (e.g., Correa, 2010; Nobre, 2001). Building up on our previous study (Capizzi et al., 2012a), we expected to replicate the finding of significant sequential effects at the P1 potential, selectively modulated by sequential effects, but not by temporal orienting. In addition, using a neutral warning signal allowed us to investigate whether the N2 and P3 modulations reported in our previous study were influenced by temporal orienting or could be taken also as putative neural markers of (automatic) sequential effects.

Method

Participants. Twenty-three students from the University of Marseille (France) took part in the experiment in exchange for cash payment of 20 Euro. All participants had normal or corrected-to-normal visual acuity and reported having normal colour vision. The study was approved by the local ethics committee and was conducted according to the guidelines of the Declaration of Helsinki. Data from eleven participants were discarded because of excessive artifacts during the EEG recording. The remaining twelve participants (age range: 18-31 years, 5 men) were used for both behavioural and ERP analyses. All participants were right-handed.

Apparatus. Stimulus presentation and response collection were controlled by a computer running t-scope (Stevens, Lammertyn, Verbruggen, & Vandierendonk, 2006). Participants were comfortably seated in an armchair placed in a Faraday cage, in a sound-shielded and dimly lit room. Two vertical handgrips on top of which response buttons were fixed were positioned on the left and right of the participant's median plane. The response buttons were to be operated with the left and right thumbs, respectively. A horizontal black panel was positioned in front of the participants, at a distance of 1 m. One light-emitting diode (LED) was fixed in the centre of the panel and was used to display the stimuli (white, red or green).

Design and Task. A trial began with the lighting of the LED in white colour for 150 ms, which acted as the warning signal (see Figure 21-A). Then, after a variable foreperiod of 850 or 1850 ms, the LED was lit either in red or in green. The participants' task was to produce a right or left button press as fast and accurately as possible to the LED colour. Half of the participants had to respond to the green LED by a right button press and to the red LED by a left button press. The other half performed the opposite stimulus-response mapping. Each foreperiod was randomly presented with the same a priori probability of appearance (i.e., P= 0.5), and was therefore preceded with similar probability by a short or long foreperiod. The

LED was turned off when participants gave their response or after a deadline of 1000 ms. The next trial began after 1500 ms. In case a premature response (i.e., before the lighting of the LED) was given, the current trial was automatically terminated and the next one was presented.

Participants completed 13 blocks of 64 trials each. The first block was considered as practice and was used by the experimenter to inform participants about their behavioural performance. Task instructions emphasized both speed and accuracy. Participants were also requested to maintain their fixation at the central LED and to avoid eye blinks and movements during stimulus presentation. The experiment lasted for about an hour. A rest between blocks of trials was allowed.

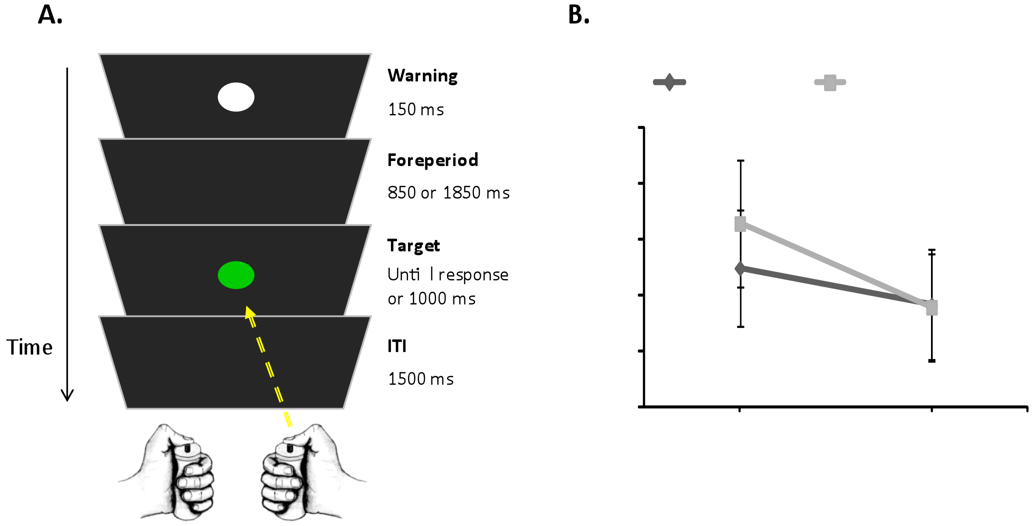


Figure 21. (A) Schematic illustration of stimuli and task. Participants had to produce a right or a left button press according to the LED (light-emitting diode) colour (green or red). ITI: Interstimulus interval. (B) Mean reaction time (RT) as a function of Current foreperiod (short, long) and Previous foreperiod (short, long). Vertical bars represent standard error of the mean.

EEG recording. The EEG was recorded from 64 Ag/AgCl electrodes (BIOSEMI, Amsterdam, The Netherlands; 10–20 system positions). The sampling rate was 1024 Hz (filters: DC to 208 Hz, 3 db/octave). Electrooculographic activity (EOG) was recorded with surface electrodes placed near both outer canthi and under the left orbit. The passive reference electrode was placed over the left mastoid.

ERP analysis. Signal processing and analysis were performed in Matlab using the EEGLAB Toolbox (Delorme & Makeig, 2004; http://sccn.ucsd.edu/eeglab/) and ERPLAB

Toolbox (http://erpinfo.org/erplab/). Data were first downsampled to 512 Hz and bandpass filtered off-line with half-power cutoffs at 0.1 and 30 Hz (non causal Butterworth infinite impulse response filter). They were then re-referenced off-line to the average to generate an accurate estimation of the scalp topography of the recorded electrical fields (Tucker, Liotti, Potts, Russell, & Posner, 1994). Independent component analysis (ICA) was performed on the continuous data to identify and remove components associated with blink activity. The ICA-corrected data were then segmented into epochs (between -200 and 600 ms) relative to stimulus onset. A strict baseline correction [−200, 50] ms was applied to each segment in order to minimize distortion of the ERP averages due to the overlap from previous events (see Woldorff, 1993). The segmented epochs were then submitted to ERPLAB artifact detection routines. At each scalp site epochs were rejected if the peak-to-peak offset exceeded 100 µV in any window of 200 ms that was moved across the entire epoch in successive steps of 50-ms. Epochs were also visually inspected, with trials containing residual artifacts removed. In addition, trials were discarded from the analysis if they contained an incorrect response. A minimum of 30 trials per condition was required to ensure a sufficient signal-to-noise ratio. For two participants PO8 channel was replaced through spherical spline interpolation (Perrin, Pernier, Bertrand, & Echallier, 1989).

Artifact-free epochs were finally averaged together according to the four conditions defined by current foreperiod (short, long) and previous foreperiod (short, long), namely, previous short − current short (SS), previous long − current short (LS), previous short − current long (SL), and previous long − current long (LL). Repeated-measures ANOVAs compared the mean amplitude of each ERP potential of interest across the experimental factors of Current foreperiod (short, long), Previous foreperiod (short, long), and Electrodes site (left, midline, right). Significant effects of Electrodes site were reported only if they interacted with either Current interval, Previous interval, or both. Time windows and electrodes sites for the analyses were chosen on the basis of visual inspection of the grand average waveforms and according to our previous study (Capizzi, Correa, & Sanabria, 2012a). The latency associated to the maximum peak was analysed only for the P3 potential within the same temporal window and electrodes site as those used for the P3 amplitude. For all analyses, the Greenhouse-Geisser correction was applied when sphericity was violated (Jennings and Wood 1976). Corrected probability values are reported.

The P1 was analysed over parietal and occipital electrodes (*left:* PO3, PO7, O1; *midline:* POz, Oz; *right:* PO4, PO8, O2) within a time window of 90-130 ms after the onset of the target. The N1 was analysed at the same electrodes as P1 between 160-200 ms. The N2 and P3 were analysed over central and parietal electrodes (*left:* CP1, CP3, P1, P3; *midline:* CPz, Pz; *right:* CP2, CP4, P2, P4) between 220-260 ms and 280-350 ms, respectively.

Results

Behavioural results. The arcsine transforms (Winer, 1970) of the error rate (1 %) and the mean RT from correct responses were submitted to a repeated-measures ANOVA with Hand (left, right), Current foreperiod (short, long) and Previous foreperiod (short, long) as within-participants factors. The behavioural analysis excluded data from practice trials, the first trial of each block and trials without responses.

The ANOVA on the error rate did not reveal any significant main effects or interactions (all Fs<1). The ANOVA on the mean RT showed a significant main effect of both Current foreperiod, $F(1, 11) = 14.15$, $p = .03$, $\eta_p^2 = .5$, and Previous foreperiod, $F(1, 11) = 12.06$, $p = .005$, $\eta_p^2 = .5$. The interaction between the two factors was also significant, $F(1, 11) = 15.62$, $p = .002$, $\eta_p^2 = .5$, revealing the typical asymmetry of sequential effects (see Figure 21-B). Planned comparisons for this interaction showed a larger effect of the previous foreperiod at the current short foreperiod, $F(1, 11) = 21.01$, $p < .001$, than at the current long foreperiod ($F<1$). The main effect of Hand was not significant and did not interact with any other factor (all ps>.15), so we collapsed the data across the two hands in the EEG analysis.

Electrophysiological results. The ANOVA on the P1 amplitude (see Figure 22) showed a significant main effect of Current foreperiod, $F(1, 11) = 6.2$, $p = .03$, $\eta_p^2 = .3$, such that the P1 amplitude was enhanced when the Current foreperiod was long (1.49 μv) as compared to when it was short (0.82 μv). The main effect of Previous foreperiod also reached statistical significance, $F(1, 11) = 6.89$, $p = .02$, $\eta_p^2 = .3$, revealing a larger P1 for a previous short (1.26 μv) than for a previous long foreperiod (1.06 μv). The interaction between the two factors was not significant ($F<1$).

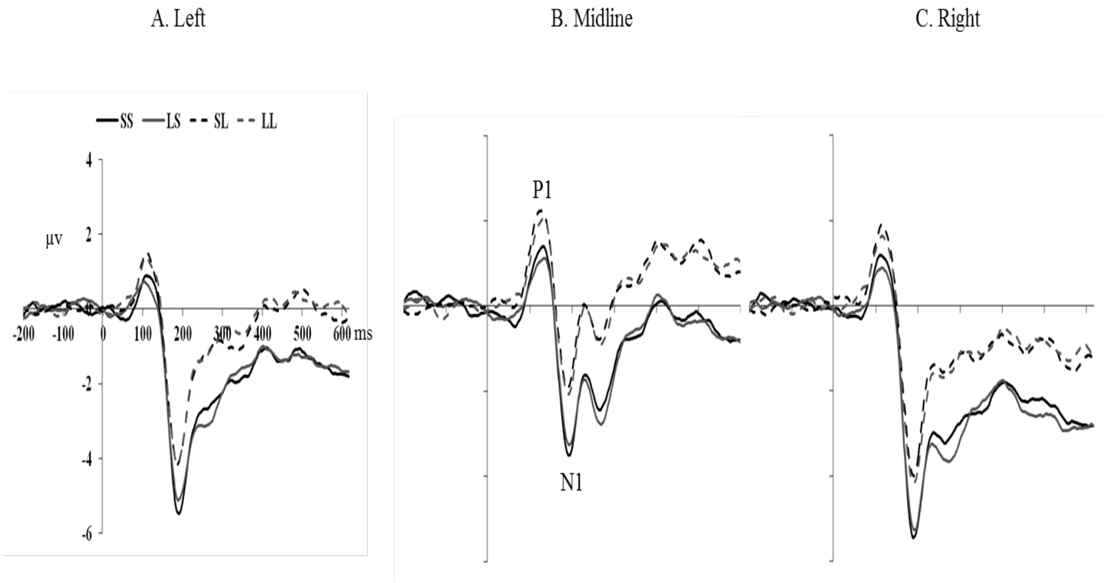


Figure 22. Grand average waveforms for the left, the midline and the right site elicited by target stimuli for previous short−current short condition (SS), previous long−current short condition (LS), previous short−current long condition (SL), and previous long−current long condition (LL). The labels show the P1 and N1 potentials.

The ANOVA on the N1 amplitude showed a significant main effect of Current foreperiod, *F*(1, 11) = 14.23, *p* =.003, η_p^2 =.5, as the N1 was attenuated after a long foreperiod (-2.94 µv) as compared to a short foreperiod (-4.17 µv). None of the other terms in the ANOVA reached statistical significance (all *ps*>.1).

The ANOVA on the N2 amplitude (see Figure 23) paralleled the N1 findings as there was a significant main effect of Current foreperiod, *F*(1, 11) = 21.14, *p* <.001, η_p^2 =.6, with attenuated N2 for a long foreperiod (1.75 µv) as compared to a short foreperiod (0.45 µv). None of the other terms in the ANOVA reached statistical significance (all *ps*>.1).

The ANOVA on the P3 amplitude (see Figure 23) showed a significant main effect of Current foreperiod, *F*(1, 11) = 29.28, *p* <.001, η_p^2 =.7, such that the P3 was enhanced for a long foreperiod (4.19 µv) as compared to a short foreperiod (2.91 µv). The interaction between Current foreperiod and Previous foreperiod was also significant, *F*(1, 11) = 5.19, *p* =.04, η_p^2 =.3. Subsequent planned comparisons for this interaction revealed that the P3 amplitude was larger following a previous short than a previous long foreperiod at the current short foreperiod, but not at the current long foreperiod [3.12 versus 2.70 µv, *F*(1, 11) = 5.28, *p* =.04, and 4.17 versus 4.22 µv, *F*<1, for the current short and the current long foreperiod, respectively].

The ANOVA on the P3 latency displayed only a significant Current foreperiod x Previous foreperiod interaction, *F*(1, 11) = 6.58, *p* =.02, η_p^2 =.3. Planned comparisons for this interaction showed that the P3 peaked earlier following a previous short than a previous long foreperiod at the current short foreperiod [327 versus 329 ms, *F*(1, 11) = 7.74, *p* =.01], but not at the current long foreperiod [327 versus 324 ms, *F*(1, 11) =1.92, *p* =.1].

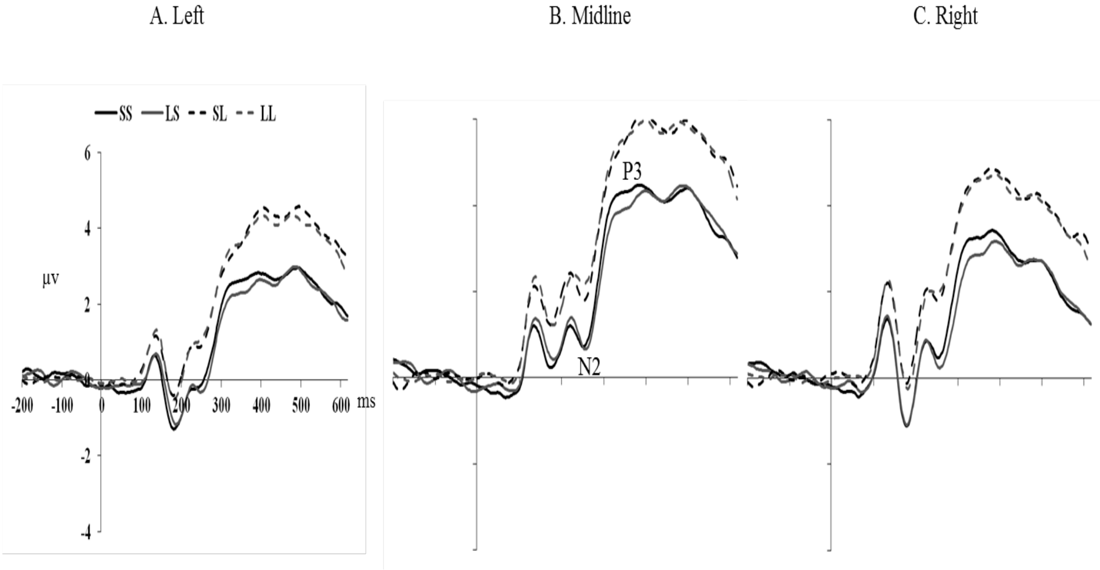


Figure 23. Grand average waveforms for the left, the midline and the right site elicited by target stimuli for previous short−current short condition (SS), previous long−current short condition (LS), previous short−current long condition (SL), and previous long−current long condition (LL). The labels show the N2 and P3 potentials.

Discussion

Sequential effects of temporal preparation, on current short trials, consist of faster responses when current and previous foreperiod match in duration (i.e., short-short sequence) than when they mismatch (long-short sequence). By contrast, on current long trials, participants' responses are equally fast for both repeating and alternating foreperiods (long-long sequence versus short-long sequence). The electrophysiological correlates of these temporal sequential effects were investigated in a variable foreperiod paradigm requiring participants to perform a colour discrimination task. The present design was critical to resolve the issue of which target processing stage is selectively modulated by sequential effects, without the influence of explicit temporal predictions at the current short foreperiod (see Capizzi et al., 2012a).

Replicating our previous study (Capizzi et al., 2012a), the P1 was affected by the duration of the previous trial, so that it was larger following a previous short rather than a previous long foreperiod. The present result could be accommodated within the framework of the dual-process model put forward by Vallesi and coworkers to account for sequential effects (Vallesi, 2010; Vallesi & Shallice, 2007; Vallesi, Shallice, & Walsh, 2007). In this model, an important factor in determining sequential effects would be the automatic arousal modulation from the previous trial. That is, a previous short foreperiod would increase participants' levels of arousal as compared to a previous long foreperiod, thus explaining the behavioural benefits observed for a short-short foreperiod sequence. Considering that the P1 potential has been shown to be sensitive to arousal changes (e.g., Vogel & Luck, 2000), it would be reasonable to speculate that such an early stage of processing might be an electrophysiological marker of the behavioural advantage conferred by a previous arousing short foreperiod. However, this explanation does not fit well with the dual-process model inasmuch as a pre-motor/motor locus instead of a perceptual locus would be predicted for the arousal effect. Such a claim is motivated by the fact that, according to the dual-process model, facilitatory mechanisms by a previous short foreperiod would emerge at the motor arousal level. That is, a previous short foreperiod would increase participants' readiness to respond, which would explain the RT advantage for short-short foreperiod sequences relative to long-short sequences. Indirect support for a pre-motor locus of sequential effects comes from evidence that patients with lesions to left premotor areas do not show the RT benefit for a current short foreperiod preceded by another short foreperiod, even in the presence of a normal foreperiod effect (Vallesi et al., 2007).

If the dual-process model cannot account for our findings of enhanced P1 amplitude following a previous short foreperiod, neither can the trace-conditioning view (Los, 1996; Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001). On this account, sequential effects would also stem from changes in motor activation occurring on the previous trial (i.e., trace-conditioning rules; see also Van der Lubbe et al., 2004, for further evidence). In any case, it is worth noting that neither the trace-conditioning model (Los, 1996; Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001) nor the dual-process model (Vallesi, 2010; Vallesi & Shallice, 2007; Vallesi, Shallice, & Walsh, 2007) have tested their assumptions by investigating which target processing stage would be modulated by sequential effects. It follows that the question as to whether supposed conditioning or arousal mechanisms could also enhance early visual processing needs to be better addressed in future studies.

Taken together with our previous findings (Capizzi et al., 2012a), we believe that an enhancement of perceptual processing by the state of preparation developed on the previous trial might be plausible. First, a significant modulation of the P1 by previous short foreperiods was replicated across two types of task, namely, a simple-RT task in Capizzi et al. (2012a) and a discrimination task as the one used in the present work. Second, an enhanced P1 was observed both in the context of a temporal orienting procedure, despite absent temporal orienting effects at early stages of perceptual processing (Capizzi et al., 2012a), and in the context of a variable foreperiod design. The consistency of these findings suggests that the modulation of the P1 by sequential effects is not a spurious result.

Moreover, previous functional imaging research has furthered the idea that temporal preparation in variable foreperiod designs may involve modulation of perceptual processes, as demonstrated by a significant activation of visual areas implicated in perceptual processing when the foreperiod changed randomly from trial to trial (Vallesi et al., 2009; see also Bueti et al., 2010). Our results support these findings by showing a significant enhancement of the P1 amplitude by the foreperiod effect (i.e., larger P1 amplitude for a current long as compared to a current short foreperiod) and extend them by revealing that such an early modulation was also influenced by the state of preparation developed on the previous trial. Nevertheless, given the novelty of our results caution must be taken in deciphering the functional meaning of this perceptual modulation by previous foreperiod duration. A complementary way to address the question as to whether sequential effects may optimize perceptual processing would be, for example, to employ high perceptual discrimination tasks using accuracy-based measures rather than simple reaction time-based measures (see Correa et al., 2005).

A more puzzling aspect of the present data concerns the N1 potential, which was attenuated for those targets occurring at current long relative to current short foreperiods. This result replicates the findings by Correa and Nobre (2008) of attenuated N1 amplitude by the foreperiod effect. Unexpectedly, however, the amplitude of the N1 potential was not modulated by the duration of the previous foreperiod. This result is inconsistent with our previous work (Capizzi et al., 2012a) reporting attenuated N1 when the previous foreperiod was short as compared to when it was long. Taking these findings into account, it is difficult to pinpoint the putative functional role of the N1 potential in sequential effects. On the one hand (see Capizzi et al., 2012a), this negative ERP deflection appeared to be sensitive to the duration of the previous foreperiod with reduced N1 amplitude for repeating trials as compared to alternating trials, in line with repetition-suppression accounts (Grill-Spector, Henson, & Martin, 2006). On the other hand, the present study failed to replicate such an N1 effect. Given that the two studies differed in the specific task requirements (i.e., simple-RT task versus colour discrimination task) and considering that the N1 potential is particularly sensitive to discrimination processes (e.g., Vogel & Luck, 2000), it would be interesting to compare directly these two task sets in order to investigate whether sequential effects on the N1 potential might be influenced by specific task requirements. In any case, it should be noted that, contrary to the N1potential, the P1 modulation was replicated under both simple detection and discrimination task demands.

When sequential effects were measured in the context of a temporal orienting procedure (Capizzi et al., 2012), there was also a significant attenuation of the N2 amplitude by a previous short foreperiod as compared to a previous long one. The N2 modulation by sequential effects observed in Capizzi et al. (2012a) was fairly similar in waveform shape and topography to those associated with temporal orienting (i.e., N2 attenuation by valid relative to invalid trials). The current data thus allowed us to clarify that when the influence of explicit temporal predictions was controlled by the substitution of a symbolic (informative) cue for a neutral warning signal, the N2 potential was not longer affected by sequential effects. Differently from sequential effects, the N2 potential was attenuated by the foreperiod effect in line with the results of Correa and Nobre (2008).

Taken together, the findings from the N1 and N2 potentials showed a neural dissociation between foreperiod and sequential effects, as only the former effect modulated activity related to target processing at these latency stages. This pattern of data does not fit with Los' trace-conditioning model (Los, 1996; Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001) stating that a single mechanism can account for both foreperiod and sequential effects. It rather supports the idea that multiple rather than a single mechanism would underlie the two temporal effects (Vallesi, 2010; Vallesi & Shallice, 2007; Vallesi, Shallice, & Walsh, 2007).

The last ERP of interest in our analysis was the P3 potential. Paralleling the behavioural data, the results from the P3 were qualified by a significant interaction between current and previous foreperiod duration. The P3 amplitude elicited by a previous short foreperiod was larger as compared to that triggered by a previous long foreperiod only when the current foreperiod was short but not when it was long. Moreover, the P3 peaked earlier for a short-short foreperiod sequence than for a long-short sequence, although this effect was quite small (2 ms). Together with the results from our previous study (Capizzi et al., 2012a) showing larger P3 amplitude for previous short as compared to previous long foreperiods, the present data suggest that sequential effects may also act on specific ERP markers of response preparation to upcoming events. This result is strengthen by the fact that the P3 amplitude modulation by sequential effects was replicated in the absence of explicit temporal predictions and under single-task and dual-task conditions (Capizzi et al., 2012a), which makes it possible to assume that the P3 potential could be a key index of temporal sequential effects (e.g., Stadler, Klimesch, Pouthas, & Ragot, 2006).

To conclude, the present study used a variable foreperiod paradigm to provide a more pure measure of the electrophysiological correlates of temporal sequential effects. In line with Capizzi et al. (2012a), we replicated the novel finding of early visual processing enhancement by previous foreperiod duration as indexed by the P1 potential. Our data also point to the P3 as a sensitive neural marker for sequential effects. All in all, these findings suggest that sequential effects may enhance both early and late stages of information processing. While the latter modulation may be easily accounted for by current models of sequential effects, the former poses a great challenge to the idea that sequential effects mainly act on motor preparation.

Chapter VII: General discussion

The main aim of the present thesis was to investigate the nature − controlled versus automatic − of the processes involved in temporal preparation. To achieve this goal, we focused on temporal orienting of attention and sequential effects. Testing how these two effects would behave in the context of a dual-task paradigm could provide an important window on the cognitive processes and neural mechanisms underlying temporal preparation. Research prior to the current thesis suggested that temporal orienting and sequential effects involve different processes of preparation on the basis of two main results: 1) they influence RTs additively (Correa, Lupiáñez, & Tudela, 2006; Correa, Lupiáñez, Milliken, & Tudela, 2004), and 2) they do not involve similar brain areas (Triviño, Correa, Arnedo, & Lupiañez, 2010). However, these dissociations only inform that temporal orienting and sequential effects may be mediated by different mechanisms, but they do not provide a direct test of their controlled versus automatic nature. The novel contribution of the present thesis is the evidence that temporal orienting would involve controlled processing, while sequential effects automatic processing. Crucially, the results of the thesis suggest a gradation rather than a strict dichotomy between controlled and automatic temporal preparation. That is, temporal orienting and sequential effects could be conceived as the extreme end points along a continuum ranging from controlled to automatic processing. The most controlled end of this continuum would be represented by temporal orienting and the most automatic end by sequential effects. Along this continuum there appears to be different gradations according to the specific experimental task context.

The General Discussion is organized into four sections. The first provides a brief overview of the main results obtained in each experimental series. The second and third sections focus on the implications that our studies have for the understanding of temporal orienting and sequential effects, respectively. The main issues requiring future research to gain a better understanding of temporal preparation are also highlighted. The last section offers an outline of the general conclusions of the present thesis.

Overview of the main results of the thesis

The current research builds up on the following criterion: if performance in a primary task is reduced by the addition of a concurrent secondary task, then the primary task would involve controlled processing. If, in contrast, people can perform equally well on both tasks, then the primary task would rely on automatic processing (e.g., Posner and Snyder, 1975). The behavioral experiments presented in Series I were conducted within this dual-task framework to address the question as to whether temporal orienting and sequential effects would depend on controlled or automatic processes. We reasoned that if temporal orienting depends on controlled processing, it should be reduced by the addition of a concurrent secondary task. By contrast, if sequential effects rely on automatic processing, they should be unaffected by dual-task demands. This prediction was tested in Experiment 1, in which temporal expectancy was manipulated between blocks of trials (i.e., “early” blocks were alternated to “late” blocks). The results of this experiment failed to confirm our hypothesis that temporal orienting would be reduced by concurrent processing demands, given that validity effects resisted to dual-task interference as much as sequential effects did.

Experiment 2 was designed to control for the possibility that the procedure by which temporal cues were manipulated in Experiment 1 might have been responsible for the lack of dual-task interference on temporal orienting. Previous research has reported that it is harder to obtain temporal orienting effects when temporal expectancy induced by the cue is manipulated on a trial-by-trial basis than when temporal expectancy remains constant within a block of trials (Correa et al., 2004). This finding has been interpreted by assuming that generating a single temporal expectancy across a block of trials is less demanding than generating a new temporal expectancy on each trial. In the former case, participants would in fact consume fewer resources since the same temporal matching (i.e., early cue-short interval versus late cue-long interval) would be used repeatedly over several trials. If this were correct, then the results of Experiment 1 would suggest that a blocked manipulation of temporal cues may lead to validity effects robust enough to survive to dual-task interference. We directly tested this possibility in Experiment 2 by manipulating temporal expectancy driven by symbolic cues on a trial-by-trial basis. Our prediction was to observe attenuated temporal orienting effects under dual-task as compared to single-task conditions, if more resources were indeed required when participants had to update their expectancy on every trial. The results of Experiment 2 confirmed selective dual-task interference between temporal orienting and working memory tasks, so that validity effects were eliminated when participants were engaged in the mental counting task. On the contrary, sequential effects were not reduced by the addition of a dual-task context.

The last study of Series I aimed at further strengthen the findings of Experiment 2 by ruling out the possibility that the elimination of temporal orienting effects, observed in our dual-task condition, was due to the fact that information necessary for carrying out both temporal orienting and working memory tasks was provided at once by the same stimulus (i.e., the cue). In other words, participants might have prioritized the encoding of cue colour information in lieu of processing the meaning of the temporal cue. To test this hypothesis, we designed Experiment 3 in which both temporal and colour information was provided by different stimuli and at different times, that is, the memory stimulus was separated from the temporal cue. The results from this control experiment confirmed the finding of reduced temporal orienting effects in the dual-task condition as compared to the single-task condition. In contrast, sequential effects again survived to dual-task interference, a finding that spoke in favor of their automatic nature.

It is interesting to note that temporal orienting effects were completely abolished when the temporal cue elicited updating of both working memory and temporal expectancy (Experiment 2), while they were present, albeit significantly reduced, when the two updating processes were separated (Experiment 3). These findings suggest a gradation of the competition for attentional resources between temporal orienting and working memory tasks, such that maximal competition would have occurred when updating of temporal expectancy and working memory took place simultaneously (Experiment 2) rather than when a brief temporal interval was allowed between the presentation of the temporal cue and the memory colour (Experiment 3). Supporting this idea of gradation, the results from Experiment 1 showed no competition between temporal orienting and working memory tasks when only updating of working memory but not of temporal expectancy was requested on a trial-by-trial basis. In contrast to temporal orienting, sequential effects survived to dual-task interference as they were neither eliminated nor reduced by concurrent extra processing demands. If anything, the results of Experiment 2 reported an enhancement but not an attenuation of sequential effects under dual-task conditions.

In the following study, Experiment 4, we used ERPs to explore at which stage of the information processing the interference between temporal preparation and working memory tasks would occur. Experiment 4 replicated the behavioural dissociation of Experiment 2 between temporal orienting and sequential effects, so that only the latter survived to dual-task demands. ERPs informed us about the locus of interference between temporal orienting and concurrent working memory updating. The analysis of preparatory activity, as indexed by the CNV, showed that the working memory task already interfered with temporal orienting at preparatory stages. The typical modulation of the CNV by temporal orienting (an “early” cue leading to more negative CNV, i.e., higher preparation, than a “late” cue at the expected moment of an early target onset; Miniussi et al., 1999) was found only in the single-task condition but not in the dual-task condition. This finding showed that participants could make effective use of the cue to prepare their response to the upcoming target only when they were not engaged in the secondary task. Otherwise, they were not able to synchronize their response readiness to target onset. Paralleling these data, the analysis of target-locked ERPs revealed a selective interference between temporal orienting and working memory tasks at late stages of target processing. Valid temporal information resulted in attenuated N2 amplitude and reduced P3 latency under single-task relative to dual-task conditions. As expected in the current design, where the task did not involve high perceptual demands (Correa et al., 2006), no modulation of early processing stages by temporal orienting was observed in either the single-task or in the dual-task condition. All in all, these results strengthened the involvement of controlled processing in the ability to orient attention in time by showing a selective interference of working memory tasks upon neural markers of temporal orienting.

A more puzzling scenario emerged for sequential effects. On the one hand, we replicated the finding of increased CNV amplitude following a previous short as compared to a previous long interval (e.g., Los and Heslenfeld, 2005; Van der Lubbe et al., 2004). On the other hand, however, such a modulation did not resist to dual-task interference. Along the same line, sequential effects attenuated the N2 amplitude and reduced the P3 latency only in the single-task but not in the dual-task condition. Such ERP pattern was similar in both topographies and waveforms shape to that observed for temporal orienting. We interpreted these data as if sequential effects were influenced by controlled factors when studied in the context of an endogenous temporal orienting procedure. The only critical difference between temporal orienting and sequential effects was observed at early visual processing stages. For the first time, we found that sequential effects selectively modulated the P1 potential. Crucially, such a P1 modulation was present to a similar degree in both the single-task and the dual-task condition. To isolate the "pure" electrophysiological correlates of sequential effects and to further investigate this unexpected influence on the P1 potential, we then designed another ERP experiment in which we substituted the predictive temporal cue for a classic warning signal. That is, the warning signal provided neutral information about the temporal onset of the target. In so doing, we aimed at reducing the potential influence of controlled temporal expectancies in the study of sequential effects.

In Experiment 5, the warning signal preceded the target, which had one of two colours that participants were to discriminate. The employment of a discrimination task instead of a simple-RT task, like the one used in Experiment 4, allowed us to test the generality of the early processing modulation by sequential effects across different task demands. The results of this study successfully replicated the P1 enhancement following a previous short rather than a previous long foreperiod. In addition to the P1 modulation, we found significant sequential effects at late stages of target processing. The P3 elicited by a previous short foreperiod was larger as compared to that triggered by a previous long foreperiod only when the current foreperiod was short but not when it was long. Taking these findings into account, we suggested that sequential effects may optimize performance through enhancement of both early and late stages of information processing.

In conclusion, the results from Series I showed that sequential effects survived to dual-task interference, while temporal orienting was reduced as a function of the competition for executive resources required by both temporal preparation and working memory tasks. The ERP findings supported this dissociation by showing that sequential effects influenced early visual potentials while temporal orienting did not. Finally, the benefit of perceptual processing by sequential effects was replicated in Experiment 5. The following sections discuss the implications of these findings for both temporal orienting and sequential effects.

Temporal orienting and dual-task interference

The last years have witnessed an increasing research interest in the field of temporal orienting of attention. Many studies have described the benefits conferred by temporal orienting for both perceptual and motor behaviour. Electrophysiological, neuropsychological and brain-imaging methods have started to unveil the neural mechanisms involved in this critical cognitive ability (e.g., Correa, 2010; Nobre, 2001). Altogether, these studies point to the flexibility of temporal orienting to optimize behaviour and suggest that such an advantage critically depends on prefrontal brain areas linked to cognitive control (e.g., Triviño, Correa, Arnedo, & Lupiañez, 2010). The findings from our thesis strengthened these conclusions and provided first direct evidence of the controlled nature of temporal orienting. We showed that temporal orienting can be reduced and even eliminated by concurrent working memory updating. Strikingly, the interference between temporal orienting and working memory tasks occurred at late stages of information processing that have been specifically linked to the ability to orient attention in time.

At this point, one might wonder: Would temporal orienting have been interfered by concurrent processing demands in the context of a different secondary task? In other words, is there anything special about the resource competition between temporal orienting and working memory? Answering this question could provide some valuable clues on the processes that support temporal preparation. The argument that temporal orienting performance may be interfered selectively by working memory tasks is bolstered by research showing that working memory and time perception rely on common right frontal structures (Harrington, Haaland, & Knight, 1998; see Lewis & Miall, 2006, for a review). Moreover, the link between temporal processing and working memory has been acknowledged in many models of time perception, as in the influential "scalar expectancy theory" (Gibbon, 1977). In its simplest form, when people have to compare the duration between a standard interval and another longer or shorter interval, a pacemaker would monitor the passage of time by producing periodic pulses. These pulses would be stored by an accumulator and then transferred to working memory. A final decision stage would compare the pulses accumulated in working memory to those already stored in a reference memory system to identify an appropriate outcome (i.e., shorter or longer duration).

Another evidence of the link between working memory and temporal processing comes from the so-called "interference effect", which was reported in the literature on dual-task and timing performance (Brown, 2010). This effect consists of more variable and inaccurate timing judgments when participants are required to perform a concurrent distractor task as compared to when they have to perform only the timing task. Importantly, a pattern of bidirectional interference, that is, an impairment of the distractor task by concurrent timing demands, has been found exclusively in experiments involving secondary tasks that require executive resources, like attentional control and memory updating. According to Brown (2010), the finding of bidirectional interference shows that both timing and other executive tasks, including memory updating, draw on the same pool of resources thus interfering with each other.

Although our experiments were not designed to test the bidirectional interference between temporal orienting and working memory tasks (there was no single-memory task condition), it is still likely that temporal orienting would be particularly sensitive to working memory demands. The rationale is that time perception, and so working memory, is involved in temporal orienting tasks although participants are not explicitly requested to estimate or reproduce a discrete duration. Nevertheless, the relationship between time perception and temporal orienting has received little attention so far. As an exception, Triviño et al. (2011) recently showed that patients with right frontal lesions exhibited a severe deficit both in a time estimation task, as indexed by a tendency to overestimate time duration, and in a temporal orienting task, as indexed by the reduction of validity effects. That overestimation might have led participants to prepare their response to the wrong moment in time. Corroborating this idea, the dual-task condition of Experiment 4 of the present thesis showed no modulation of temporal orienting on both CNV and P3 amplitudes in a similar way to what has been reported in experiments where participants had to discriminate between two durations under augmented cognitive load (Gontier et al., 2007). Taking these findings into account, it might be possible that time perception would play a more critical role in the ability to orient attention in time than previously acknowledged. This research avenue should be explored in future research, in which dual-task methodology would provide an excellent tool, for example, by comparing whether time estimation and temporal orienting tasks would be affected to the same degree under dual-task demands.

Another result that informed us about the interference between temporal orienting and working memory tasks is offered by the findings from Experiment 1 of the present thesis. Such experiment showed that a block-wise instruction to orient attention in time did not harm validity effects under concurrently working memory updating. Building up on this evidence, we proposed that a blocked-manipulation of temporal expectancies might involve more automatic rather than exclusively controlled processing. It follows that the balance between controlled and automatic processing in temporal orienting of attention critically depends on the way temporal information is provided. But, what would happen if instead of manipulating the amount of resources required by temporal orienting, we manipulated the load imposed by the working memory task? In other words, would participants be able to shift their temporal expectancy on a trial-by-trial basis if the secondary task would be a less demanding memory task? According to our proposal of a gradation of competition between temporal preparation and working memory tasks, we would predict that manipulating the amount of resources required by the secondary task would also influence temporal orienting effects. To test this hypothesis, we performed a pilot experiment in which we manipulated working memory load by intermixing "updating trials" with "rehearsing trials". The experimental design was similar to that used in Experiment 3 of the present thesis. The key difference was that each block contained both updating trials, in which participants had to update the count of three colours, and rehearsing trials, in which the memory stimulus was not displayed, so that participants did not have to update any of the three memory target colours. This latter condition required participants to engage in a less demanding rehearsing task to maintain the final count of the colours until the end of the block. We predicted that temporal orienting effects based on a within-trials manipulation of temporal expectancies should suffer from greater interference when participants had to update their working memory contents as compared to when they had to engage in a less demanding rehearsal task. Our preliminary data support this prediction by showing a significant reduction of temporal orienting effects on the updating trials but not on the rehearsing trials.

Together with the main findings of Experiments 1-3 of the thesis, the results of the experiment described above reinforce the idea that temporal orienting is especially sensitive to extra processing working memory demands. As described earlier, the involvement of common brain areas in working memory, time perception and temporal orienting tasks (i.e., the right prefrontal cortex; Lewis & Miall, 2006; Triviño et al., 2010) lends anatomical support to this claim. At any rate, it would be informative to further explore whether temporal orienting would be impaired by other secondary tasks that do not involve working memory in order to strengthen the pattern of results shown here. Another complementary manipulation to explore the interference between temporal orienting and working memory updating would be to substitute the simple-RT task that was used in the experiments of the present thesis for a demanding discrimination task. In so doing, we would predict to obtain a significant modulation of early visual potentials (P1) by temporal orienting as that observed by Correa et al. (2006). The working hypothesis here is to investigate whether working memory updating would also affect these early visual markers of temporal orienting in addition to the dual-task disruption of the N2 and P3 potentials reported in Experiment 4. If so, we could obtain more evidence of a selective interference between temporal orienting and concurrent working memory demands.

As last point, we believe that future research should investigate the role that individual differences might play in both temporal orienting and working memory tasks. In particular, an objective measure of working memory capacity would enable to compare the effects of temporal orienting between participants with high and low working memory span. Some predictions can be made. On the one hand, given the role of working memory in time perception, as described earlier, we would expect participants with a high memory span to perform better in the temporal orienting task in the single-task condition. Likewise, these participants might also have more executive resources available to perform the temporal orienting task even under dual-task demands. On the other hand, we would predict participants with a low memory span to perform poorly on both temporal orienting and working memory tasks under each task condition. These predictions must be tested in future studies by employing an objective measure of working memory capacity.

To sum up, the data of the present thesis provide direct evidence that temporal orienting of attention is mediated by controlled processes on condition that participants have to shift their temporal expectancies on a trial-by-trial basis. By contrast, when a single expectancy has to be generated and maintained along the whole block, temporal orienting tasks may be accomplished in a more automatic manner. This pattern of results is consistent with the view that the distinction between controlled and automatic processing in temporal preparation should be perceived as a flexible continuum rather than as a strict dichotomy. Among the factors that can affect such a continuum is the way in which temporal information is provided as well as the amount of executive resources required by the secondary task. A fruitful direction for future research is to clarify the role of time perception in temporal orienting performance and to test the generality of dual-task interference on temporal orienting across different secondary tasks. Finally, individual differences in working memory capacity could tell us more about how controlled processing is implemented in temporal orienting tasks.

Sequential effects and dual-task interference

In contrast to temporal orienting, a more challenging picture exists with regard to our current knowledge about sequential effects of temporal preparation. This gap may be due to the fact that little attention has been paid to sequential effects as compared to temporal orienting. So, while we know that temporal orienting relies on participants' expectancy as to when the target stimulus would occur and that such ability largely depends on right prefrontal cortex functioning (e.g., Triviño et al., 2010), we do not know definitely where sequential effects come from at both the behavioural and neural levels. The two most influential models developed to explain sequential effects, namely the trace-conditioning view (Los, 1996; Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001) and the dual-process view (Vallesi, 2010; Vallesi & Shallice, 2007; Vallesi, Shallice, & Walsh, 2007), converge on the idea that sequential effects would result from automatic processing, whereas they diverge significantly on the origin of such automatism.

The trace-conditioning view proposed that automatic processing for sequential effects would be determined by a set of conditioning rules that operate implicitly across trials. Importantly, these rules could be applied to explain both sequential and foreperiod effects. By contrast, in the dual-process view automatic processing would be triggered by motor arousal modulation from a previous short foreperiod, so that a short-short foreperiod sequence would lead to faster RT relative to a long-short sequence. This arousal effect would operate regardless of the duration of the current foreperiod. However, at the current long foreperiod it would be masked by the controlled influence of the time-monitoring process checking the conditional probability of target occurrence over time (i.e., foreperiod effect). It follows that foreperiod and sequential effects would arise from partly dissociable mechanisms.

In agreement with these two models, the results of our behavioural series reinforced the general view of sequential effects as the outcome of automatic temporal preparation. However, the notion of automaticity does not imply that an automatic process has to be cognitively impenetrable or "encapsulated" (cf. Fodor, 1983). This view bears some similarities to the attentional capture literature (see Ruz & Lupiáñez, 2002, for a review). In visual search tasks where participants have to search for a defined target among a variable number of distractors, the presence of a singleton (i.e., an irrelevant item that is unique in some dimension) can automatically capture attention to its spatial location. However, it has been shown that attentional capture can also be either suppressed or enhanced by specific attentional sets. These studies thus raise important questions about the notion of automaticity by suggesting that some processes, even if automatic by default, can be sensitive to controlled factors. All in all, our data point to this direction. On the one hand, the finding of unaffected sequential effects under dual-task conditions in our first behavioural series strengthened the dissociation between sequential effects and temporal orienting. Moreover, they provided direct evidence that the two effects would be mediated by different processes. On the other hand, when the behavioural data were complemented by higher temporal resolution ERP measures, a rather different pattern emerged. Unexpectedly, sequential effects differed from temporal orienting only at early stages of processing, as indexed by the P1 potential that was sensitive to the duration of the previous trial but not to the temporal information triggered by a valid prediction. This P1 modulation for sequential effects resisted to dual-task interference. The involvement of perceptual processing in sequential effects was also corroborated across different tasks (temporal orienting procedure with a simple-RT task and variable foreperiod paradigm with a discrimination task).

Understanding the involvement of perceptual processing in sequential effects will be a major challenge for the current models of temporal preparation, as both the trace-conditioning view and the dual-process view suggest a pre-motor/motor locus for sequential effects rather than an early perceptual locus (e.g., Los & Heslenfled, 2005; Vallesi, Mussoni et al., 2007). Indeed, we believe that replicating an early modulation by the duration of the previous foreperiod would not be as surprising as it may seem at first. We base our prediction on some previous work that, despite did not investigate sequential effects, lends indirect support to our data. First, activation of visual areas implicated in perceptual processing has been associated with a variable foreperiod design in brain-imaging research (Vallesi et al., 2009; see also Bueti et al., 2010). These findings suggest that temporal preparation in variable foreperiod paradigms may enhance perceptual processes, as further corroborated by our findings of increased P1 amplitude by the foreperiod effect (i.e., larger P1 amplitude for a current long as compared to a current short foreperiod). Second, increasing evidence has been accumulated showing that high temporal preparation acts on perceptual stages of the stimulus-response chain by accelerating the beginning of perceptual processing of the upcoming stimulus (i.e., "early onset hypothesis"; Rolke & Hofmann, 2007; see also Correa, Sanabria et al. 2006). These authors challenged the prevailing view that temporal preparation mainly act at late stages within the stimulus-response stream by showing that temporal preparation may enable a more accurate analysis of sensory information. We believe that this line of research should be pursued in future behavioural studies on sequential effects by stressing accuracy-based measures rather than speed-RT measures (see Correa et al., 2005). Another challenge for research on sequential effects and temporal orienting would be to find the missing part of the double dissociation between them. Namely, it would be informative to identify which factors would impair the automatic aspect of temporal preparation by leaving the controlled part unaffected.

To sum up, our data strengthen the prevailing view that sequential effects are the product of automatic, albeit not "encapsulated", processes of temporal preparation. According to our findings, sequential effects may optimize behaviour by enhancing early perceptual processing stages as indexed by the P1 potential. Such an early modulation cannot be easily accounted for by current models of sequential effects. At this point, a main issue remains unsolved. How can sequential effects optimize performance? Our proposal is that sequential effects would improve behaviour since they would act as a rhythmic pattern. It has been shown that the presentation of a regular sequence of events, i.e., a rhythm, can induce temporal preparation automatically (e.g., Large & Jones, 1999; Rohenkohl, Coull & Nobre, 2011; Sanabria, Capizzi, & Correa, 2011). A neuropsychological study has reported that patients with right frontal damage, who usually have intact sequential effects, could not orient attention in time by means of symbolic cues, while they were not impaired if time was cued implicitly by means of a regular rhythm (Triviño et al., 2011). These findings demonstrate that automatic temporal preparation, as induced by a rhythm can overcome the temporal orienting deficit in right frontal patients by facilitating the use of implicit temporal information.

In order to test the nature of the processes involved in temporal preparation driven by rhythms, we recently used a dual-task paradigm as that adopted in the present thesis (de la Rosa, Sanabria, Capizzi, & Correa, 2012; Experiment 1). The results of this study showed that participants could benefit from the presentation of a regular rhythm to optimize their performance under both single-task and dual-task conditions. Such a pattern of findings provides evidence that temporal preparation driven by rhythms does not require resources of executive control. In addition, it has been shown that rhythmic patterns may optimize performance by enhancing perceptual processing (e.g., Doherty et al., 2005; Sanabria & Correa, under review). Building up on these similarities between rhythmic patterns and sequential effects, it makes sense to hypothesize that sequential effects might function as a “rhythm” that can automatically entrain the system to optimize performance. Future studies will explore this possibility.

Before concluding this section of the General discussion a last issue should be discussed. The data from Series I and II showed that participant’ responses under the dual-task condition were particularly impaired at the short time interval as compared to the long interval. So, one might wonder what these findings can tell us about the foreperiod effect (i.e., faster RT at the long interval as compared to the short interval). As described earlier, temporal orienting and foreperiod effects are thought to reflect the operation of a common mechanism based on the strategic computation of conditional probabilities over time (e.g., Correa & Nobre, 2008). As a matter of fact, the behavioural effects produced by these two sources of temporal predictions interact significantly, as indexed by the fact that validity effects are strong at the short interval and reduced (or absent) at the long interval. The attenuation of validity effects may be accounted for by the involvement of time-monitoring processes, which would reduce the behavioural cost of an invalid prediction at the long interval.

Contrary to the view of a common mechanism for both effects, our data showed a significant modulation of the foreperiod effect by dual-task demands, but in the opposite direction as that displayed by temporal orienting. The foreperiod effect indeed increased, instead of decreasing as expected, under dual-task conditions. This result was driven by the fact that the secondary task deteriorated performance more severely at the short rather than at the long foreperiod. The finding of stronger dual-task interference at the short foreperiod than at the long foreperiod could be due to the less time available to complete both working memory updating and rehearsal of the colours in short versus long foreperiods. Nevertheless, the finding of a steeper foreperiod effect under dual-task conditions still persisted in Experiment 3, in which more time was allowed between the presentation of the memory stimulus and the occurrence of the short foreperiod. Overall, our findings suggest that the foreperiod effect, taken as an RT index, may not be an optimal candidate to study controlled temporal preparation. Rather, it should be acknowledged that the foreperiod effect survived to dual-task manipulation in our experiments, which might be taken as evidence against its controlled nature (see also Van Lambalgen & Los, 2008, for similar conclusions). The use of different secondary tasks or foreperiod distributions in future research would be particularly useful to address further this question.

General conclusions

1. The current results provide direct behavioural and electrophysiological evidence of the controlled nature of temporal orienting.
2. They also show for the first time that a different amount of executive resources might be involved in a blocked-manipulation as compared to a within-trials manipulation of temporal expectancies.
3. These results favor the idea that the balance between controlled and automatic processing in temporal preparation should be perceived as a flexible continuum rather than as a strict dichotomy.
4. The behavioural dissociation between temporal orienting and sequential effects shows that sequential effects are mediated by automatic processing.

5. The neural overlap between temporal orienting and sequential effects at late stages of information processing extends current knowledge on sequential effects by showing that, albeit automatic in nature, sequential effects can be also susceptible of modulation by controlled factors. This pattern of data reinforces the idea that there are no rigid boundaries between controlled and automatic temporal preparation.

6. The finding of sequential effects at early visual processing stages suggests that sequential effects may optimize performance through enhancement of perceptual processing. This result challenges the current models sequential effects

7. The study of sequential effects without the influence of explicit temporal predictions reinforces the idea that perceptual processing can be sensitive to the state of preparation developed on the previous trials.

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