Section 3b

Temporal predictions guided by endogenous cues

Chapter 26

Enhancing behavioural performance by visual temporal orienting

Ángel Correa

Tempus omnia revelat
(Latin proverb: time will reveal all things)

Temporal orienting of attention belongs to the general field of research on 'temporal expectations'. Temporal expectation involves a prediction about when a forthcoming event will occur. As defined by Coull and Nobre (1998), temporal orienting concerns 'how information about time intervals can be used to direct attention to a point in time when a relevant event is expected, to optimise behaviour' (p.7426). This chapter will focus on studies of temporal orienting, in which expectations are induced by cues providing explicit and predictive information about the temporal onset of a task-relevant stimulus ('target'). I will describe the behavioural consequences of temporal orienting through a variety of tasks demanding specific aspects of cognitive processing, such as perception, action, language, and executive control. The main message of these sections is that temporal orienting facilitates the processing of task-relevant stimulus representations flexibly, through a broad spectrum of cognitive processes. Finally, temporal orienting is discussed in a broader context, in relation to other types of temporal expectations that guide attention. The picture here reveals rich interrelations between attentional preparation and different types of temporal information.

A brief history of temporal orienting

The origins of temporal orienting can be traced back to the first studies about attentional preparation, in the early days of Experimental Psychology as a scientific discipline (Wundt, 1887). Early scholars observed the essential role of time in attentional preparation by manipulating the duration of the preparatory interval, the so-called 'foreperiod'. They showed that preparation develops over time and relies on temporal certainty about the target onset (Woodrow, 1914).

The closest antecedent to investigations of temporal orienting is probably the study by Zahn and Rosenthal (1966). In this study, two foreperiods of different durations (1 and 3 seconds) were randomly intermixed during the experiment. The key manipulation concerned the distribution or relative proportion of these foreperiods, which could be either biased to the short duration (high probability of 1-second foreperiods), biased to the long duration (high probability of 3-second foreperiods), or unbiased (equal probability of 1-second and 3-second foreperiods). Reaction times (RTs) to detect a target were collected and then plotted as a function of foreperiod duration ('RT-foreperiod functions') for each condition of foreperiod distribution. Although participants received no information about the duration and distribution of foreperiods, the three RT-foreperiod functions clearly revealed differential temporal-expectancy profiles.

The critical finding was that the distribution biased toward short intervals strongly decreased RTs at the short foreperiod, as if a high proportion of short foreperiods induced an early expectancy, which tuned temporal preparation optimally to the short interval.

Could participants voluntarily use these temporal expectations if they were based on explicit information about when a target would appear? This question gave birth to the formal study of the temporal orienting of attention. A decade ago, Coull and Nobre (1998) conducted a neuroimaging study with positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) to address this question. In an analogous manner to what had happened in the general field of time perception (see Macar et al., 2002, for a review), the neural approach followed by Nobre and her colleagues contributed to the renaissance of the classical field of temporal preparation in the contemporary context of Cognitive Neuroscience. Since that initial study (Coull and Nobre, 1998) the number of publications on temporal orienting has grown continually and exponentially.

Box 26.1 Temporal expectations outside the laboratory: three everyday examples

Example 1: little David got sick and his mum took him to the nursery. David was very anxious, as he knew he would be given an injection. However, the experienced nurse played the following trick. She started counting: 'One, two, and . . .' and suddenly, she gave the injection; '. . . and three?' asked David with surprise and relief, as he felt much less pain than he had anticipated. Why did the nurse give him the injection earlier than expected? She was applying one principle of temporal orienting: perception (in this case, the perception of pain) is impaired for stimuli occurring at unexpected times. The nurse induced in David a late expectancy about the occurrence of the painful injection, but she 'delivered' the pain before that moment. Distracting attention away from the actual moment of the delivery of pain served to attenuate the perception of pain.

Example 2: 'Ready . . .'—the athletes were perfectly lined up behind the starting line. 'Steady . . .' the expectation dramatically increased millisecond by millisecond in the stadium, the athletes increased their readiness to the maximum: muscles taut, attention highly focused, awaiting the auditory go signal . . . 'Bang!'—Carl Lewis was the first athlete who started running. He reacted just 250 milliseconds after hearing the gunshot, and most important, 50 milliseconds earlier than the second runner. What was the secret of his temporal advantage? Carl was very good at orienting his attention to the exact moment at which the gun fired. With his attention temporally tuned, he was the fastest participant to perceive the sound, and the fastest one to trigger the motor activity of his leg muscles. That crucial advantage helped Carl win that race.

Example 3: one day, there was general confusion in the office about the onset of a meeting. Immanuel believed it would start at 10:30. Helen said the right meeting time was 11:00, whereas Rose expected the meeting to happen at 11:30. There was nobody at the office when Immanuel arrived. He was prepared to start at 10:30, but had to delay that moment for at least half an hour. During that time interval, Immanuel thought: 'sooner or later the meeting will take place today, so I am going to rehearse my speech one more time'—thus, he became fully prepared for the meeting even though its onset did not confirm his initial temporal expectation. The boss arrived at 11:00 and the meeting started. Helen appeared on

Box 26.1 Temporal expectations outside the laboratory: three everyday examples *(continued)*

time, she was prepared and her speech was hence excellent. Immanuel also did a good job when his turn began since he was also prepared—well, strictly speaking, he was re-prepared. Poor Rose received a phone call from her boss at 11:15. 'Damn! I needed those fifteen minutes for the final rehearsal of my speech!'—Rose arrived late and unprepared for the meeting, which was evident from her speech. 'If only I could go back in time' she lamented. As she realized that people can only prepare for the future, not for the past, she decided to follow the same strategy as Immanuel. For the next meeting, Rose would be ready on time, and in fact, a bit earlier!

Temporal orienting speeds up motor responses

Can attention be oriented to specific moments in time, analogously to the orienting of attention in the spatial domain? Coull and Nobre (1998) developed a temporal version of the Cost and Benefits procedure, introduced by Posner (1980) to study how attention could be oriented covertly to different locations in space (see also Coull, Chapter 31; Nobre, Chapter 27, this volume). In a temporal-orienting procedure (see Figure 26.1), a temporal cue explicitly indicates that the task-relevant stimulus ('target') will appear either after a short interval ('early') or after a long interval ('late'). Temporal cues are predictive, since in most trials the early cue is validly associated with target onsets at the short interval, whereas the late cue is related to target onsets at the long interval. When the target appears (e.g. the 'X' stimulus), participants have to respond as quickly as possible by pressing a key. That is, they perform a speeded simple-RT detection task.

The results typically show that the early cue produces the fastest RTs at the short interval, whereas the late cue produces the fastest RTs at the long interval. These opposite temporal-expectancy profiles can be attributed to the predictive temporal information explicitly provided by the cues. 'Temporal orienting effects' are generally indexed by comparing early versus late cue conditions at the short interval only. In Figure 26.1, temporal orienting effects refer to faster RTs to detect expected targets at the short interval as compared to RT to detect earlier-than-expected targets also appearing at the short interval. At the long interval, however, temporal orienting effects are diminished or absent because they are masked by another form of temporal expectation, foreperiod effects (see Los, Chapter 21; Vallessi, Chapter 22, this volume). Following our example, the target could occur either at the short or at the long interval with similar a priori probability (p = 0.5). However, the *conditional probability* of target occurrence increases with time, such that the target always appears at the long interval (p = 1) if it has not yet appeared at the short interval. Obviously, explicit temporal cues are more effective when they serve to predict uncertain rather than certain target onsets (i.e. in short-interval rather than long-interval conditions; see 'Temporal orienting in relation to other forms of temporal expectation' section for further details). To summarize, we can conclude that temporal orienting optimizes behaviour by speeding up performance in detection tasks (Coull and Nobre, 1998).

AQ: Please check if see 'Temporal orienting in relation to other forms of temporal expectation' section for further details, is ok (was 'see Section 5', but sections not numbered here)

But what was the nature of this behavioural enhancement? Was it due to faster perception or to faster responses to the target stimulus? The answer was clear according to the initial evidence based on fMRI and event-related potentials (ERPs): temporal orienting speeds up behaviour by enhancing the preparation of motor responses (Coull and Nobre, 1998; Miniussi et al., 1999; Coull et al., 2000; Nobre, Chapter 27, this volume). The implication was that the effects of temporal orienting were constrained to modulating the preparation of motor processing. However, this interpretation did not fit with the general view of attention as a mechanism that selects information flexibly, not only at late response stages, but also at early perceptual stages of

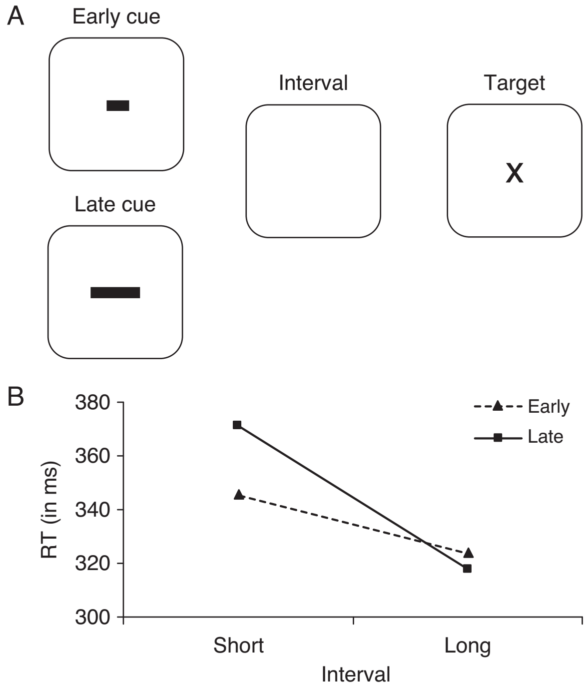

Fig. 26.1 A) How to study temporal orienting. A standard temporal-orienting experiment is composed of a set of trials. Each trial includes a sequence of a temporal cue, interval, and target, which can be visually presented to the participants via computer screen. The temporal cue provides explicit and predictive information about the time interval after which the target will appear. The short bar in the figure indicates that the target will appear after 400ms with a probability of 0.75, whereas the long bar indicates that the target will appear after 1400ms with the same probability. On each trial, only one temporal cue is presented, which is followed by a blank interval. The duration of this interval can be either short (400ms) or long (1400ms) with equal probability. In 'valid' trials, the target appears at the cued interval (early cue—short interval and late cue—long interval conditions). In 'invalid' trials, the target appears either earlier than expected (late cue—short interval) or later than expected (early cue—long interval) according to the temporal cue. The participants' task is to detect the letter 'X' (i.e. target) and press a key as quickly as possible (simple-RT detection task). B) Typical results in temporal orienting experiments. Mean reaction times (RTs) averaged across participants are plotted as a function of temporal cue (early, late) and interval (short: 400ms; long: 1400ms). Note that RTs are faster for long, as compared to short, intervals; this is the 'foreperiod effect'. Most importantly, the early expectation induced by the temporal cue attenuates the slope of the foreperiod effect. As a result, RTs at the short interval are faster for early cues rather than for late cues; this is the 'temporal orienting effect' (or validity effect). In contrast, RTs at the long interval are generally similar for both early and late cues, which reflect the interaction between temporal orienting and foreperiod effects. The facilitation in task performance at cued intervals is ascribed to the orienting of attention to the interval specified by the temporal cue. Procedure and data are taken from Correa, Á., Lupiáñez, J., Milliken, B., and Tudela, P. (2004). Endogenous temporal orienting of attention in detection and discrimination tasks. *Perception and Psychophysics,* **66**(2), 264–78.

stimulus processing. In fact, the possibility that temporal orienting could also influence early perceptual analysis had been acknowledged in the first two review articles that Nobre and colleagues published about temporal orienting (Griffin, Miniussi, and Nobre, 2001; Nobre, 2001). However, empirical evidence was still needed to support this hypothesis. The search for evidence of temporal orienting effects upon perceptual processing had just begun.

Temporal orienting improves stimulus perception

Why did the initial studies fail to observe perceptual enhancement by temporal orienting? An answer to this intriguing question could be found in research showing that spatial orienting enhances stimulus perception through the visual system (see Mangun, 1995, for a review). The visual system is rich in spatial rather than temporal information, as it is spatially organized following retinotopic maps. Given that all temporal orienting studies had so far been conducted in the visual modality only, it was possible that the tasks were not sensitive enough to show perceptual modulation. Perhaps, temporal orienting effects would be most clearly observed if a temporally rich modality, such as audition, was involved. Following this logic, Lange and her colleagues found that temporal orienting enhanced the auditory N1, an ERP component linked to early perceptual analysis of auditory information (Lange, Rösler, and Röder, 2003; Lange and Röder, Chapter 28, this volume).

At that time, my colleagues and I realized that the evidence restricting the effects of temporal orienting to motor preparation in the visual modality was exclusively based on simple-RT detection tasks. These tasks emphasize the execution of a speeded response, but do not require a detailed perceptual analysis of the visual features of the target. This circumstance could have favoured the effect of attention upon response rather than perceptual levels of processing. The use of tasks imposing stronger demands on perceptual analysis might instead strengthen the beneficial effects of attention on stimulus perception.

For example, choice-RT discrimination tasks require that participants respond selectively to target stimuli that differ along a particular perceptual feature, such as shape. In a shape discrimination task, participants should make one response if they see 'X', and a different response if they see 'O'. Indeed, the behavioural findings in visual discrimination tasks suggested that temporal orienting might enhance the perceptual analysis of visual stimuli (Griffin et al., 2001; Los and Van den Heuvel, 2001; Milliken et al., 2003; Correa et al., 2004). However, these findings relied on RT measures, in which it is difficult to isolate the contribution of perceptual versus motor factors to the attentional benefits that were observed. Thus, faster RT performance for attended versus unattended targets in a discrimination task could be due to faster stimulus perception (perceptual preparation), faster responses (motor preparation), or both. Behavioural indices other than RT were therefore necessary to investigate temporal orienting effects on perceptual preparation. To that end, an appropriate index should be a measure of perceptual processing that is collected free from time pressure during participants' responses.

The use of psychophysical methods can provide behavioural indices of perceptual accuracy, such as d′ (Green and Swets, 1966). In a first study (Correa, Lupiáñez, and Tudela, 2005), we used rapid serial visual presentation (RSVP), in which the target (the 'X' letter) was embedded within a stream of distractors (other letters). The participants' task was to decide (without time pressure) whether the target had been presented in the stream. This task was perceptually challenging, as stimuli were successively presented so fast (14ms per item) that they masked one another. We explicitly cued participants to attend to the specific points in time at which the target could appear, and tested whether d′ improved as a consequence of these temporal expectations. The results showed that visual perception, as indexed by d′, was most accurate for targets appearing at the cued temporal interval (Correa et al., 2005). This finding provided the first behavioural evidence that temporal orienting improves visual perception (see also Rolke and Ulrich, Chapter 17, this volume).

In a later study we used another measure of perceptual accuracy uncontaminated by response time pressures to gain convergent evidence that temporal orienting improves visual perception (Correa et al., 2006a). Participants performed a 'temporal order judgment' task, in which they had to judge (without time pressure) the order of occurrence of two peripheral flashes presented very close in time (ranging from 10–110-ms separation). The dependent variable of interest was the 'just noticeable difference (JND)'—the minimum temporal separation between the onsets of the two stimuli allowing correct report of their order of occurrence with 75% accuracy. Therefore, a smaller JND indicated better temporal resolution. We instructed participants to attend selectively to the interval indicated by the cue, and tested whether the JND decreased with valid temporal expectations. The results showed that the JND was smaller for targets appearing at the expected interval (JND = 41ms) as compared to the unexpected interval (JND = 46ms). In other words, temporal orienting improved the temporal resolution to perceive the order of two visual events that occurred almost simultaneously.

Supporting these findings, there is growing evidence from electrophysiological studies demonstrating facilitation of perceptual-related ERPs by temporal orienting (Doherty et al., 2005; Correa et al., 2006b, 2007; Lange, Krämer, and Röder, 2006; Sanders and Astheimer, 2008; Lange, 2009). A key feature that emerges after reviewing these studies is the common use of tasks involving strong demands on perceptual processing (see Correa et al., 2006b, for a review). This set of studies was important to temporal-orienting research, not only because they proved the flexible nature of the underlying attentional mechanism, but also because they enriched the range of cognitive tasks used to study temporal orienting. The initial simple-RT tasks were replaced by increasingly sophisticated tasks to address complex phenomena in human cognition. This idea is illustrated in the following section, which describes research on the effects of temporal orienting upon linguistic processing and executive control.

Temporal orienting beyond perception and action: effects on semantic processing and executive control

Does the flexibility of temporal orienting go beyond the modulation of simple perceptual and motor representations? The studies described in this section show that temporal orienting also influences high-level central cognition, such as linguistic processing of semantic categories and the executive control needed to perform complex selection of competing stimuli and responses.

Semantic processing can be studied by measuring priming effects produced by a stimulus (prime) upon the processing of a subsequent stimulus (target), with which it shares a semantic category. A study by Naccache and colleagues (Naccache, Blandin, and Dehaene, 2002) found that temporal orienting can facilitate semantic categorization, as indexed by unconscious semantic priming effects. Semantic priming was measured at the unconscious level by embedding primes and targets within a RSVP of visual masks. Specifically, semantic priming was only observed when the prime and target occurred within the attended time window, which suggests that temporal orienting facilitates semantic processing. Another study using RSVP found that temporal orienting also facilitated the conscious identification of target letters presented within a stream of distractor digits (Martens and Johnson, 2005). Furthermore, the main result of that study was that temporal cuing reduced the attentional blink (Raymond, Shapiro, and Arnell, 1992; Shapiro and Raymond, Chapter 3; Olivers, Chapter 4, this volume). This interesting finding

AQ: Please confirm the setting of running head here.

JTC: OK

suggests that temporal orienting can optimize the deployment of attentional resources at critical time intervals, in order to overcome the temporal limitations of working memory.

In most studies mentioned so far, the attentional selection of cognitive representations was relatively simple, that is, it did not involve controlled selection of mutually competing representations. Competing or incompatible representations produce conflict during information processing, which can be resolved by executive control according to internal goals (Atkinson and Shiffrin, 1968; Norman and Shallice, 1986). For example, executive control is engaged during the resolution of response conflict in the flanker task (Eriksen and Eriksen, 1974). In the arrows-version of this task, participants have to respond according to whether the direction of a central arrow (target) points left or right. Response conflict arises in the incongruent condition, in which a set of arrows flanking the target points in the opposite direction (e.g. ‘> > < > >’). Controlled selection is then needed to inhibit the response associated with the incompatible flankers and/or to activate the response associated with the target. In contrast, the congruent condition does not involve response conflict because target and flankers call for the same response (e.g. ‘< < < < <’). When task performance is compared for congruent and incongruent conditions (i.e. the *conflict effect* index), it becomes clear that controlled selection is difficult and time-consuming (i.e. errors are more frequent and RTs are slower on incongruent as compared to congruent conditions).

We have recently started investigating the effects of temporal orienting upon executive control processes required to resolve between conflicting representations during task performance. The results of the first study showed temporal orienting to have different effects depending on whether the task involves conflicting representations at the perceptual-selection or motor-selection levels (Correa et al., in press). Temporal orienting *facilitated* executive control when the task involved the resolution of conflict at *perceptual* rather than response levels, such as in the spatial Stroop task. In the incongruent condition of the spatial Stroop task, perceptual conflict arises from a mismatch between two stimulus dimensions, target location and orientation (e.g. a target arrow is presented at the top of the display—meaning ‘up’, whereas the arrow is pointing downwards—meaning ‘down’).

However, temporal orienting *disrupted* rather than facilitated the resolution of *response conflict* as indexed by flanker and Simon (Simon and Small, 1969) tasks. In the incongruent condition of the Simon task, response conflict arises from a mismatch between the location at which a stimulus is presented and the side of the motor response specifically associated with that stimulus according to task instructions (e.g., a target is presented in the left visual field, whereas the participant has to use the right hand to respond correctly to that target). In this particular condition, participants committed many more errors when the conflicting target appeared at the *attended* rather than the unattended moment. Do these puzzling findings imply that temporal orienting impairs executive control? They at least suggest that the enhancement of response readiness conferred by temporal orienting is only beneficial when simple response selection is required (e.g. in simple-RT detection tasks; Coull and Nobre, 1998), but not when the controlled selection of competing response tendencies is involved. Research on temporal orienting effects upon executive control is still in the initial phase; forthcoming studies should explore temporal orienting with other types of executive-control tasks.

The preceding sections have addressed the question of the locus of temporal orienting effects. We have concluded that this locus is flexible, and mainly depends on the cognitive demands of the task at hand. Another important question that has emerged in the field concerns the relationship between temporal orienting and other time-related attentional processes. The following section will focus on the interrelationship between temporal orienting and other forms of temporal expectation.

Temporal orienting in relation to other forms of temporal expectation

Temporal expectation is a broad concept that includes multiple types of attentional preparation in time. Temporal expectations can rely on many different sources to provide the relevant temporal information, such as explicit predictive cues (temporal orienting), temporal regularity (rhythmic expectations), probabilistic information associated with the passage of time (hazard functions and foreperiod effects), and inter-trial sequences of repetitions/alternations of foreperiod durations (sequential effects). However, the interrelationship between different types of temporal expectations has been considered only recently (see Nobre, Correa, and Coull, 2007; Coull and Nobre, 2008, for reviews). Foreperiod effects refer to the finding of faster RTs at long as compared to short foreperiods (i.e. preparatory intervals) in variable foreperiod procedures, in which short and long foreperiods are intermixed within a block of trials (Los, Chapter 21; Vallesi, Chapter 22, this volume). Sequential effects refer to the finding that RTs are faster when the current short foreperiod is a repetition of a previously short foreperiod rather than a switch from a previously long foreperiod (Woodrow, 1914; see also Los, Chapter 21, this volume). Rhythmic expectations refer to the finding that optimal task performance occurs at time intervals coinciding with a regular rhythm (Jones et al., 2002; see also, Olson and Chun, 2001; Jones, Chapter 23; Praamstra, Chapter 24; Schubotz, Chapter 25, this volume).

The diversity of these phenomena included under the concept of temporal expectations naturally calls for a taxonomy. One possible criterion to divide them considers the implicit versus explicit nature of the source of temporal prediction. Explicit temporal expectations are produced by temporal orienting, whereas implicit temporal expectations are produced by foreperiod effects, sequential effects, and rhythmic expectations, since they occur naturally regardless of the participant's explicit knowledge about underlying temporal contingencies. Alternatively, temporal expectations can be classified as a function of the automatic versus controlled nature of the processing underlying the behavioural effects (Los and Van den Heuvel, 2001; Capizzi, Sanabria, and Correa, 2009).

Capizzi and colleagues recently tested the automaticity of different types of temporal expectations by asking participants to perform a temporal preparation task, similar to the task shown in Figure 26.1, under both single-task and dual-task conditions. In the latter condition, we found that the addition of a concurrent working memory task interfered selectively with temporal orienting and foreperiod effects; in contrast, sequential effects survived to dual-task interference (Capizzi, Sanabria, and Correa, 2009). This result supports the idea that temporal orienting and foreperiod effects involve controlled temporal expectations since they both: 1) are influenced by a working memory task that competes for limited resources of controlled processing (Posner and Snyder, 1975); 2) rely on the strategic computation of conditional probabilities over time (Correa and Nobre, 2008); and 3) engage prefrontal brain areas linked to attentional control (Coull and Nobre, 1998; Coull et al., 2000; Stuss et al., 2005; Vallesi, Shallice, and Walsh, 2007; Vallesi et al., 2007, 2009) (see also Vallesi, Chapter 22; Coull, Chapter 31, this volume).

On the other hand, sequential effects and rhythmic expectations involve automatic temporal expectations, as they can guide temporal expectation in a bottom-up manner solely on the basis of non-predictive stimuli (Los and Van den Heuvel, 2001; Jones et al., 2002; Steinborn et al., 2008). Moreover, automatic sequential effects are immune to a competing working memory task (Capizzi, Sanabria, and Correa, 2009), and they probably involve brain structures: 1) that follow an earlier development in life than the prefrontal cortex (Vallesi and Shallice, 2007; Vallesi, Chapter 22, this volume) and 2) that might be involved in processes of trace conditioning (Los and Van den Heuvel, 2001; Los, Chapter 21, this volume).

As can be observed, the two suggested taxonomies are highly overlapping, such that sequential effects and rhythmic expectations are considered to involve implicit and automatic processing, whereas temporal orienting involves explicit and controlled processing. More research in this area should improve this taxonomy and clarify the relationships between different types of temporal expectations. In this context, some studies have already revealed that temporal orienting and sequential effects exert dissociable consequences on behaviour (Correa et al., 2004; Los and Van den Heuvel, 2001; Los and Agter, 2005; Los and Heslenfeld, 2005; Correa, Lupiáñez, and Tudela, 2006).

The dissociation between temporal orienting and sequential effects has been further supported by a recent study, in which we analysed the controlled versus impulsive nature of prepared responses by testing whether they could be successfully inhibited in a go-nogo response inhibition task (Triviño et al., 2007). The results showed that temporal orienting enhanced both response speed and executive control for appropriate response inhibition, whereas sequential effects increased response speed but impaired response inhibition. This dissociation hence supports the conclusion that temporal orienting induces controlled response preparation, while sequential effects elicit automatic preparation based on fast impulsive reactions. Moreover, foreperiod and sequential effects have also been dissociated at the neural level in lesion studies (Vallesi, Shallice et al., 2007; Vallesi et al., 2007; Vallesi, Chapter 22, this volume). Instead, other studies find strong interactions rather than dissociations between different forms of temporal expectation, namely, between temporal orienting and foreperiod effects (Correa, Lupiáñez, and Tudela, 2006, see also Figure 26.1), and between rhythmic expectations and foreperiod effects (Correa and Nobre, 2008).

Recently, we have developed a simple experimental task that can be administered to neuropsychological patients in order to evaluate functioning of three types of temporal expectations (temporal orienting, foreperiod and sequential effects), and to study the interaction between them (Triviño et al., 2007). The task consists of an adaptation of the task shown in Figure 26.1. The preliminary results obtained with this task seem promising: patients with frontal lesions presenting frontal symptoms in neuropsychological testing were impaired on temporal orienting and foreperiod effects, whereas sequential effects remained intact. This finding hence confirms the association between temporal orienting and foreperiod effects (suggesting a common mechanism), and the dissociation between temporal orienting/foreperiod effects versus sequential effects. This neurological dissociation also fits well with the taxonomy in which sequential effects reflect automatic processing, whereas temporal orienting and foreperiod effects reflect controlled processing dependent upon the prefrontal cortex. Taking into account the interaction between temporal orienting and foreperiod effects, temporal orienting can be understood as the explicit and controlled modulation of the foreperiod effect.

Conclusions

The main conclusion to be drawn from this chapter is that temporal orienting is a mechanism that selects information with a high degree of *flexibility*. Temporal orienting can prioritize both perceptual and motor processing, depending on the types of representations that are particularly task-relevant within a specific context. The benefits of temporal orienting upon behavioural performance seem *widespread*, as they are evident across a variety of behavioural tasks involving low- as well as high-level cognitive demands. These attributes of temporal orienting fit perfectly with the notion of selective attention, with the particularity that the selection of information is controlled by explicit predictions about the temporal onset of events.

References

Atkinson, R. and Shiffrin, R. (1968). Human memory: a proposed system and its control processes. In K. Spence and J. Spence (Eds.) *The Psychology of Learning and Motivation: Advances in Research and Theory*, Vol. 2, pp.742–75. New York: Academic Press.

Capizzi, M., Sanabria, D., and Correa, A. (2009). 'Dual-task evidence for automatic and controlled mechanisms in temporal preparation.' Paper presented at the XVI Conference of the European Society for Cognitive Psychology, Krakov (Poland). 2–5 September, 2009.

Correa, Á. and Nobre, A. C. (2008). Neural modulation by regularity and passage of time. *Journal of Neurophysiology,* **100**(3), 1649–55.

Correa, Á., Triviño, M., and Lupiáñez, J. (under review). To shoot or not to shoot now: Temporal preparation and impulsivity.

AQ: Is there any update for the Correa, Trivino, and Lupianez (under review) paper please?

Correa, Á., Lupiáñez, J., and Tudela, P. (2005). Attentional preparation based on temporal expectancy modulates processing at the perceptual-level. *Psychonomic Bulletin and Review,* **12**(2), 328–34.

Correa, Á., Lupiáñez, J., and Tudela, P. (2006). The attentional mechanism of temporal orienting: Determinants and attributes. *Experimental Brain Research,* **169**(1), 58–68.

Correa, Á., Lupiáñez, J., Milliken, B., and Tudela, P. (2004). Endogenous temporal orienting of attention in detection and discrimination tasks. *Perception & Psychophysics,* **66**(2), 264–78.

Correa, Á., Lupiáñez, J., Madrid, E., and Tudela, P. (2006). Temporal attention enhances early visual processing: A review and new evidence from event-related potentials. *Brain Research,* **1076**(1), 116–28.

Correa, Á., Sanabria, D., Spence, C., Tudela, P., and Lupiáñez, J. (2006a). Selective temporal attention enhances the temporal resolution of visual perception: Evidence from a temporal order judgment task. *Brain Research,* **1070**(1), 202–5.

Correa, Á., Kane, R., Lupiáñez, J., and Nobre, A. C. (2007). 'Temporal orienting facilitates perception: Electrophysiological evidence based on steady-state visual evoked potentials.' Paper presented at the XV Conference of the European Society for Cognitive Psychology, Marseille (France). 29 August–1 September, 2007.

Correa, Á., Cappucci, P., Nobre, A. C., and Lupiáñez, J. (in press). The two sides of temporal orienting: facilitating perceptual selection, disrupting response selection. *Experimental Psychology*.

Coull, J. T. and Nobre, A. C. (1998). Where and when to pay attention: the neural systems for directing attention to spatial locations and to time intervals as revealed by both PET and fMRI. *Journal of Neuroscience,* **18**(18), 7426–35.

Coull, J. T. and Nobre, A. (2008). Dissociating explicit timing from temporal expectation with fMRI. *Current Opinion in Neurobiology,* **18**, 1–8.

Coull, J. T., Frith, C. D., Buchel, C., and Nobre, A. C. (2000). Orienting attention in time: behavioural and neuroanatomical distinction between exogenous and endogenous shifts. *Neuropsychologia,* **38**(6), 808–19.

Doherty, J. R., Rao, A., Mesulam, M. M., and Nobre, A. C. (2005). Synergistic effect of combined temporal and spatial expectations on visual attention. *Journal of Neuroscience,* **25**, 8259–66.

Eriksen, B. A. and Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics,* **16**, 143–9.

Green, D. M. and Swets, J. A. (1966). *Signal Detection Theory and Psychophysics*. New York: Wiley.

Griffin, I. C., Miniussi, C., and Nobre, A. C. (2001). Orienting attention in time. *Frontiers in Bioscience,* **6**, 660–71.

Jones, M. R., Moynihan, H., MacKenzie, N., and Puente, J. (2002). Temporal aspects of stimulus-driven attending in dynamic arrays. *Psychological Science,* **13**(4), 313–19.

Lange, K. (2009). Brain correlates of early auditory processing are attenuated by expectations for time and pitch. *Brain and Cognition,* **69**(1), 127–37.

Lange, K., Krämer, U. R., and Röder, B. (2006). Attending points in time and space. *Experimental Brain Research,* **173**(1), 130–40.

Lange, K., Rösler, F., and Röder, B. (2003). Early processing stages are modulated when auditory stimuli are presented at an attended moment in time: an event-related potential study. *Psychophysiology,* **40**, 806–17.

Los, S. A. and Agter, F. (2005). Reweighting sequential effects across different distributions of foreperiods: Segregating elementary contributions to nonspecific preparation. *Perception & Psychophysics,* **67**(7), 1161–70.

Los, S. A. and Heslenfeld, D. J. (2005). Intentional and unintentional contributions to nonspecific preparation: Electrophysiological evidence. *Journal of Experimental Psychology: General,* **134**, 52–72.

Los, S. A. and Van den Heuvel, C. E. (2001). Intentional and unintentional contributions to nonspecific preparation during reaction time foreperiods. *Journal of Experimental Psychology: Human Perception and Performance,* **27**, 370–86.

Macar, F., Lejeune, H., Bonnet, M., Ferrara, A., Pouthas, V., Vidal, F., et al. (2002). Activation of the supplementary motor area and of attentional networks during temporal processing. *Experimental Brain Research,* **142**, 475–85.

Mangun, G. R. (1995). Neural mechanisms of visual selective attention. *Psychophysiology,* **32**, 4–18.

Martens, S. and Johnson, A. (2005). Timing attention: cuing target onset interval attenuates the attentional blink. *Memory and Cognition,* **33**(2), 234–40.

Milliken, B., Lupiáñez, J., Roberts, M., and Stevanovski, B. (2003). Orienting in space and time: Joint contributions to exogenous spatial cuing effects. *Psychonomic Bulletin and Review,* **10**(4), 877–83.

Miniussi, C., Wilding, E. L., Coull, J. T., and Nobre, A. C. (1999). Orienting attention in time: modulation of brain potentials. *Brain,* **122**, 1507–18.

Naccache, L., Blandin, E., and Dehaene, S. (2002). Unconscious masked priming depends on temporal attention. *Psychological Science,* **13**(5), 416–24.

Niemi, P. and Näätänen, R. (1981). Foreperiod and simple reaction time. *Psychological Bulletin,* **89**, 133–62.

Nobre, A. C. (2001). Orienting attention to instants in time. *Neuropsychologia,* **39**, 1317–28.

Nobre, A. C., Correa, A., and Coull, J. T. (2007). The hazards of time. *Current Opinion in Neurobiology,* **17**, 1–6.

Norman, D. A. and Shallice, T. (1986). Attention to action: willed and automatic control of behaviour. In R. J. Davidson, G. E. Schwartz, and D. Shapiro (Eds.), *Consciousness and Self-Regulation: Advances in Research and Theory* (pp.1–18). New York: Plenum Press.

Olson, I. R., and Chun, M. M. (2001). Temporal contextual cuing of visual attention. *Journal of Experimental Psychology: Learning, Memory and Cognition,* **27**(5), 1299–313.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology,* **32**, 3–25.

Posner, M. I., and Snyder, C. R. R. (1975). Attention and cognitive control. In R. Solso (Ed.), *Information processing and cognition: The Loyola Symposium*, pp.55–85. Hillsdale, NJ: Lawrence Erlbaum.

Raymond, J. E., Shapiro, K. L., and Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance,* **18**(3), 849–60.

Sanders, L. D. and Astheimer, L. B. (2008). Temporally selective attention modulates early perceptual processing: event-related potential evidence. *Perception & Psychophysics,* **70**(4), 732–42.

Simon, J. R. and Small, A. J. (1969). Processing auditory information: interference from an irrelevant cue. *Journal of Applied Psychology,* **53**(5), 433–5.

Steinborn, M. B., Rolke, B., Bratzke, D., and Ulrich, R. (2008). Sequential effects within a short foreperiod context: Evidence for the conditioning account of temporal preparation. *Acta Psychologica,* **129**(2), 297–307.

Stuss, D. T., Alexander, M. P., Shallice, T., Picton, T. W., Binns, M. A., Macdonald, R., et al. (2005). Multiple frontal systems controlling response speed. *Neuropsychologia,* **43**(3), 396–417.

Triviño, M., Arnedo, M., Correa, A., Funes, M. J., and Lupiáñez, J. (2007). *Temporal orienting after frontal damage*. Paper presented at the XV Conference of the European Society for Cognitive Psychology, Marseille (France). 29 August–1 September, 2007.

Vallesi, A., and Shallice, T. (2007). Developmental dissociations of preparation over time: deconstructing the variable foreperiod phenomena. *Journal of Experimental Psychology: Human Perception and Performance,* **33**(6), 1377–88.

Vallesi, A., Shallice, T., and Walsh, V. (2007). Role of the prefrontal cortex in the foreperiod effect: TMS evidence for dual mechanisms in temporal preparation. *Cerebral Cortex,* **17**(2), 466–74.

Vallesi, A., Mussoni, A., Mondani, M., Budai, R., Skrap, M., and Shallice, T. (2007). The neural basis of temporal preparation: insights from brain tumor patients. *Neuropsychologia,* **45**(12), 2755–63.

Vallesi, A., McIntosh, A. R., Shallice, T., and Stuss, D. T. (2009). When time shapes behaviour: fMRI evidence of brain correlates of strategic preparation over time. *Journal of Cognitive Neuroscience* **21**(6), 1116–26.

Woodrow, H. (1914). The measurement of attention. *Psychological Monographs,* **17**, 1–158.

Wundt, W. (1887). *Grundzüge der Physiologischen Psychologie*. Leipzig: Engelmann.

Zahn, T. P., and Rosenthal, D. (1966). Simple reaction time as a function of the relative frequency of the preparatory interval. *Journal of Experimental Psychology,* **72**, 15–19.

Acknowledgements

The writing of this chapter was supported by grants from the RYC-2007-00296 Ramón y Cajal programme, SEJ2007-63646 and SEJ2007-63247 (Spanish Ministerio de Ciencia e Innovación), and the CSD2008-00048 CONSOLIDER INGENIO (Dirección General de Investigación).