Research Article

The Two Sides of Temporal Orienting

Facilitating Perceptual Selection, Disrupting Response Selection

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Abstract. Would it be helpful to inform a driver about *when* a conflicting traffic situation is going to occur? We tested whether temporal orienting of attention could enhance executive control to select among conflicting stimuli and responses. Temporal orienting was induced by presenting explicit cues predicting the most probable interval for target onset, which could be short (400 ms) or long (1,300 ms). Executive control was measured both by flanker and Simon tasks involving conflict between incompatible responses and by the spatial Stroop task involving conflict between perceptual stimulus features. The results showed that temporal orienting facilitated the resolution of perceptual conflict by reducing the spatial Stroop effect, whereas it interfered with the resolution of response conflict by increasing flanker and Simon effects. Such opposite effects suggest that temporal orienting of attention modulates executive control through dissociable mechanisms, depending on whether the competition between conflicting representations is located at perceptual or response levels.

Keywords: attention, temporal expectation, temporal preparation, cognitive control, conflict, compatibility, cuing, flanker, spatial Stroop, Simon

Many human activities require executive control to perform complex selection between competing stimuli and responses, for example, driving. It is then important to investigate what cognitive factors may influence executive control. This article describes two experiments showing that temporal orienting of attention influences executive control. "Temporal orienting" involves the use of explicit information predicting the onset of events to focus attention voluntarily to a relevant temporal interval (Coull & Nobre, 1998). Coull and Nobre (1998) studied temporal orienting by presenting cues that indicated the most probable interval after which a target stimulus would appear. As a result, targets were detected more quickly when they appeared at intervals that were cued correctly (valid condition) rather than incorrectly (invalid condition). This so-called "validity effect" is normally larger or restricted to the short interval, since invalid targets appearing at the long interval can be fully anticipated on the basis of conditional probability (Correa, Lupiáñez, & Tudela, 2006).[1] These findings show that temporal orienting facilitates behavior by speeding up task performance.

Studies of temporal orienting have also specified that the facilitation of stimulus processing can occur flexibly, either at the early perceptual level (see Correa, Lupiáñez, Madrid, & Tudela, 2006, for a review; Correa, Lupiáñez, & Tudela, 2005; Correa, Sanabria, Spence, Tudela, & Lupiáñez, 2006; Doherty, Rao, Mesulam, & Nobre, 2005; Lange & Röder, 2006; Lange, Rösler, & Röder, 2003; Sanders & Astheimer, 2008) or at the late response level (Correa & Nobre, 2008; Coull, Frith, Buchel, & Nobre, 2000; Griffin, Miniussi, & Nobre, 2002; Miniussi, Wilding, Coull, & Nobre, 1999; see Nobre, 2001, for a review). However, the studies so far have investigated the effects of temporal orienting only within the context of relatively simple selection of stimuli and responses. The tasks have relied on simple stimulus detection with speeded responses or discrimination with arbitrary stimulus-response mappings, and have not demanded executive control to resolve strong competition between alternative stimulus or response representations. Thus, the possible effects of temporal orienting upon the resolution of conflict at perceptual and motor levels remain to be investigated.

[1] Studies showing validity effects at the long interval by manipulating the conditional-probability function (e.g., nonaging distribution) and/or including catch trials (trials where no target is presented; e.g., see Correa, Lupiáñez, & Tudela, 2006) confirm the flexibility and selectivity of temporal orienting of attention. Note that the analyses and main results presented in this article are focused on the short interval, since we did not include such manipulations.

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The current study aimed to test whether temporal orienting could facilitate executive control, as measured by three different conflict tasks involving competition at different levels of processing. Experiment 1 used the classical flanker task (Eriksen & Eriksen, 1974), which engages conflict mainly at the response level.[2] Experiment 2 used the Simon-Stroop task (Liu, Banich, Jacobson, & Tanabe, 2004) to specify further whether temporal orienting influences the resolution of conflict located at the response level (Simon) and at the perceptual stimulus level (spatial Stroop) (see Lu & Proctor, 1995, for a review). Given the previous research showing that temporal orienting enhances perceptual and motor processing, our main hypothesis considered that temporal orienting would also enhance executive control as revealed by a reduction of the conflict effect in conflict tasks.

Experiment 1

Experiment 1 combined temporal cuing with a flanker task to test whether temporal orienting can facilitate the resolution of response conflict.

Method

Participants

Sixteen students (aged: 19–24, three men) from the University of Granada took part voluntarily in Experiment 1. The study was conducted following ethical guidelines from the University of Granada.

Apparatus and Stimulus

Stimuli presentation and data collection were controlled by E-prime software (Schneider, Eschman, & Zuccolotto, 2002). All stimuli were presented in black over a gray background on a 17-in. monitor. The fixation display consisted of a central fixation point (a plus sign of 0.5° × 0.5°). The temporal cue consisted of one Spanish word (either "PRONTO" or "TARDE", respectively, meaning "early" and "late"), which appeared at the center of the screen and subtended about 2.4° horizontally. The target display consisted of five arrows (1.4° × 1° each) appearing in a row and centered on the fixation point. The direction of the central arrow (left or right) could be the same (congruent) or different (incongruent) from that of the lateral arrows (flankers). All flankers pointed in the same direction. The responses were given by pressing "z" or "m" key on the computer keyboard. Feedback regarding incorrect responses was delivered by presenting the word "Incorrect" and a 2,000-Hz auditory tone for 50 ms.

Procedure

Participants were seated at a viewing distance of about 60 cm. They were instructed to respond, as quickly and accurately as possible, to the direction of the central arrow while ignoring the flanking arrows. Participants were encouraged to maintain fixation at the center and to use the temporal cue throughout the experiment.

Each trial began with the fixation point presented for a random interval ranging between 400 and 900 ms. The cue then replaced the fixation point and remained on the screen for 500 ms. The fixation point was presented again for an interval of either 400 or 1,300 ms, depending on the interval duration condition (short, long). The target display then appeared until the participant responded or for a maximum duration of 3,000 ms. Audiovisual feedback was delivered on either misses or incorrect responses for 300 ms (on correct responses, a blank display was displayed, instead). Finally, a blank display of 400 ms preceded the next trial.

The experiment included one practice block and 10 experimental blocks. The practice block included 14 trials with early cues followed by 14 trials with late cues (100% valid). The experimental blocks were divided into five "early" blocks, in which the cue indicated that the target would probably appear after 400 ms, and five "late" blocks, in which the cue indicated that the target would probably appear after 1,300 ms (cue validity: 75%). Temporal expectancy was manipulated between blocks to optimize the finding of robust temporal orienting effects, according to previous research (Correa, Lupiáñez, & Tudela, 2006). Blocks of early and late cues were presented in alternating runs, and the order of presentation was counterbalanced across participants. Each experimental block included 38 trials that were randomly presented. Six of them were catch trials, in which the flankers were presented without the target, so that the participant had to withhold responding. The remaining 32 trials were divided according to target-flanker *congruency* (16 congruent and 16 incongruent trials) and *temporal cuing* validity (24 valid and 8 invalid trials). In the valid condition, the cue was early and the target appeared after an *interval* of 400 ms. In the invalid condition, the cue was early and the target appeared after an interval of 1,300 ms. Likewise, the late cue was paired with the 1,300-ms interval in valid trials, whereas it was paired with the 400-ms interval in invalid trials.

Results

Errors were very infrequent (1.85%) and could not be analyzed further. The reaction time (RT) analysis excluded responses faster than 200 ms or slower than 2,000 ms, trials with errors, and trials following an error (3.9% rejected). Mean RTs were submitted to a repeated-measures analysis

[2] Some studies have suggested that flanker tasks can involve stimulus conflict in addition to response conflict (e.g., Yeh & Eriksen, 1984). The present results, however, suggested that both flanker and Simon conditions involved conflict at the response level (see also Botvinick et al., 2001; Treccani, Cubelli, Sala, & Umilta, 2009).

Table 1. Mean RT and error percentages (between brackets) as a function of *conflict type* (S-R flanker task – Experiment 1, S-R Simon and S-S Stroop tasks – Experiment 2), target-distractor *congruency* (congruent, incongruent), *interval* duration (400 ms – short, 1,300 ms – long), and temporal *cuing* (valid, invalid)

		Short interval		Long interval	
Conflict task	Congruency	Valid	Invalid	Valid	Invalid
Flanker	Congruent	432 (0.7)	458 (0)	444 (1.1)	444 (0.6)
	Incongruent	470 (4.4)	483 (2.8)	488 (2.9)	483 (2.2)
Simon	Congruent	572 (5.4)	588 (6.6)	587 (5.2)	589 (3.3)
	Incongruent	605 (16.3)	611 (10)	610 (15.1)	620 (16.2)
Spatial Stroop	Congruent	599 (10.5)	591 (7.9)	617 (7.7)	618 (11.6)
	Incongruent	611 (12.1)	633 (14.2)	633 (11.3)	628 (11.9)

of variance (ANOVA) with the factors of interval duration (400, 1,300), temporal cuing (valid, invalid), and congruency (congruent, incongruent). Table 1 includes RT and error data from the eight experimental conditions.

The RT analysis showed a significant main effect of congruency, $F(1, 15) = 62.96$, $p < .001$, such that RTs were faster for congruent versus incongruent trials (i.e., the "conflict effect"). The amount of conflict effect was computed by subtracting performance on congruent from incongruent conditions and then used as an index of the efficiency to solve conflict. The effect of temporal cuing was also significant, $F(1, 15) = 10.18$, $p = .006$, yielding faster RTs for valid versus invalid trials (validity effect). Most important, temporal cuing modulated the conflict effect (Cuing × Congruency: $F(1, 15) = 8.33$, $p = .01$). Specific analyses of this interaction showed larger cuing effects on congruent (validity effect: 13 ms; $F(1, 15) = 17.25$, $p < .001$) than on incongruent conditions, where the validity effect was far from significant (validity effect: 4 ms; $F(1, 15) = 1.17$, $p = .29$). As shown in Figure 1, the conflict effect was larger for valid cuing, $F(1, 15) = 70.5$, $p < .001$, versus invalid cuing, $F(1, 15) = 42.64$, $p < .001$.

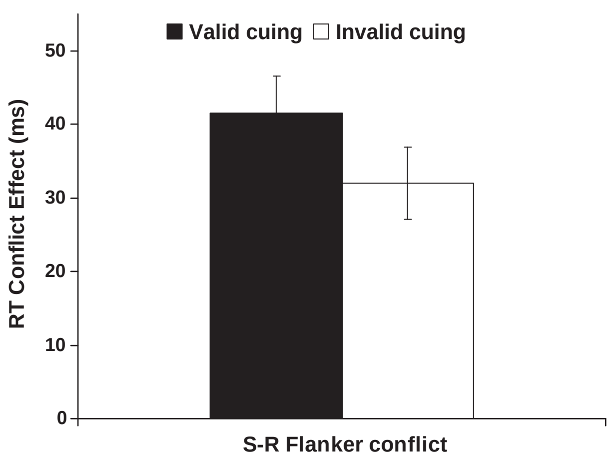

Figure 1. Flanker task of Experiment 1. Temporal orienting effects on conflict resolution as indexed by the conflict effect (RT-incongruent minus RT-congruent conditions). Mean conflict effect for RTs is plotted as a function of temporal cuing (valid, invalid). Data from short and long intervals are collapsed in this figure. Vertical bars represent standard errors. Temporal orienting increased response conflict as measured by the flanker task.

Not surprisingly, the interaction between temporal cuing and interval duration was significant, $F(1, 15) = 11.41$, $p = .004$, leading to validity effects only at the short interval, $F(1, 15) = 20.05$, $p < .001$, but not at the long interval ($F < 1$). The interaction between interval duration and congruency was also significant, $F(1, 15) = 8.33$, $p = .01$, showing larger conflict effects at long versus short intervals.

Discussion

Experiment 1 tested whether temporal orienting induced by explicit and predictive temporal cues facilitates cognitive control related to complex selection between competing responses. The efficiency for controlled response selection was indexed by the size of the conflict effect in a flanker task. The main finding of Experiment 1 was surprising, as temporal orienting modulated response selection by increasing instead of decreasing the conflict effect.

It could be argued that temporal orienting enhanced response preparation (Nobre, 2001), which incremented indiscriminately the level of activation of the responses associated with both target and flankers. Unspecific activation is beneficial when both target and distractors call for the same response, as occurred in the congruent condition. In the incongruent condition, however, unspecific preparation of the two conflicting responses would increase competition and therefore add *noise* (i.e., conflict) to a response-selection mechanism based on a threshold of response activation (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001). In other words, excessive response readiness may have not been beneficial when a conflict had to be previously solved. This explanation was supported by the finding of temporal cuing effects only on congruent but not on incongruent conditions. Temporal cuing hence strengthened response readiness, which facilitated simple response selection but interfered with controlled selection of competing response tendencies.

From Experiment 1, we can conclude that temporal orienting influences complex response selection. Experiment 2 was designed to determine whether temporal orienting could also influence the selection of competing perceptual representations, and to compare the effects with those on response selection directly.

Experiment 2

Experiment 2 further specified the effects of temporal orienting upon conflict resolution by placing the locus of competition at two different levels of processing. Conflict could arise either at the response level (as in Experiment 1) or at the stimulus level (perceptual conflict). We measured these two types of conflict simultaneously with the "Simon-Stroop" task (Liu et al., 2004; Lupiáñez & Funes, 2005). In the Simon-Stroop task, participants discriminate the spatial orientation of a stimulus, that is, whether an arrow points upward or downward, by responding with their left and right index fingers. In every trial, the target arrow can appear at one of four possible peripheral locations (left, right, up or down) relative to a central fixation point (see Figure 2).

In trials where the target appears in the horizontal axis, response conflict is indexed by the Simon effect (S-R conflict). The Simon effect is computed by subtracting performance on congruent trials (e.g., the arrow appeared at the left and the correct response was assigned to the left hand) from performance on incongruent trials, in which there was a mismatch between stimulus side and response side (note that the orientation of the arrow was orthogonal and irrelevant in this case). In trials where the target appears in the vertical axis, perceptual conflict is indexed by the spatial Stroop effect (S-S conflict). The spatial Stroop effect is computed by subtracting performance on congruent trials, in which there is a match between the two stimulus dimensions – location and orientation (e.g., the arrow appears at the top location and points upward) from performance on incongruent trials, in which there is a mismatch between stimulus location and orientation (in this case, response side is orthogonal and irrelevant).

According to Experiment 1, which showed that temporal orienting impaired the resolution of response conflict, we expected to replicate that temporal cuing increased the conflict effect in the response-conflict Simon condition. Furthermore, the most interesting condition of Experiment 2, perceptual-conflict Stroop, tested (1) whether temporal preparation modulates postperceptual processing associated with the controlled selection of competing stimulus features, and if so, (2) whether such modulation follows similar or differential patterns as compared to response conflict. Previous research has already shown that Simon tasks engage prefrontal brain areas associated with response conflict, response selection and planning, whereas spatial Stroop tasks engage inferior parietal brain areas mainly associated with perceptual biasing of task-relevant attributes (Liu et al., 2004). Hence, it makes sense to expect differential attentional modulations on these two types of conflict. As mentioned in the introduction, research showing that temporal orienting enhances perceptual preparation during perceptually demanding tasks (Correa, Lupiáñez, Madrid, et al., 2006) guided our prediction that temporal orienting would reduce the conflict effect in the spatial Stroop task.

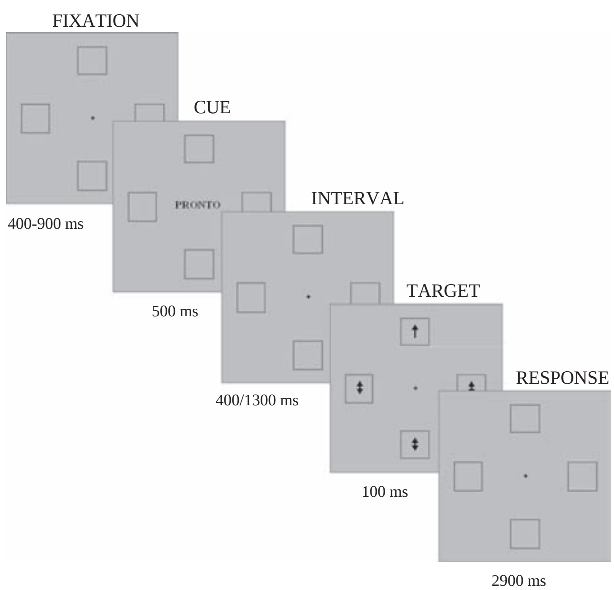

Figure 2. Example of the sequence of events in a spatial Stroop congruent trial of Experiment 2.

Method

Participants

Twenty-four female students (aged: 19–25) participated voluntarily in Experiment 2. Data from one participant were rejected due to an excessively high rate of misses (54%).

Apparatus and Stimulus

The fixation display consisted of a central fixation point surrounded by four placeholders (2.7° × 2.7° each), which were symmetrically located along the horizontal *X*-axis and the vertical *Y*-axis (Figure 2). The distance between the center of each placeholder and the fixation point was 3.8°. The target display consisted of a one-head arrow (target) pointing up or down, which appeared in one of the four placeholders, and three double-head arrows (distractors) pointing both up and down, which appeared in the three remaining placeholders. Everything else was similar to Experiment 1.

Procedure

The participants' task was to respond to the direction of the target arrow by pressing the "z" key when it pointed up and the "m" key when it pointed down. This S-R assignment was counterbalanced across participants. The general procedure was similar to Experiment 1, except for the following modifications. The target display was presented for 100 ms. Next, the fixation display remained present until the participant responded, or for a maximum duration of 2,900 ms. The experiment included two practice blocks of 16 trials and 14 experimental blocks of 32 trials. Cue validity was similar to Experiment 1 (75%). There were no catch trials. Trials were equally divided according to the *type of* *conflict* (S-R Simon, S-S Stroop). The Simon conflict condition corresponded to when the target arrow appeared on the horizontal axis. The location of the target arrow (left, right) could be either congruent or incongruent with the location of the correct responding hand. The spatial Stroop conflict condition corresponded to when the target arrow appeared on the vertical axis. The orientation of the target arrow (up, down) could be either congruent or incongruent with the location at which the target arrow was presented.

Results

Responses faster than 200 ms or slower than 2,000 ms were rejected from the analyses (0.7% rejected). The RT analyses did not include trials with errors or trials following an error (20.4% rejected). Mean RTs and error percentages were submitted to separate ANOVAs with the factors of type of conflict (Simon, spatial Stroop), interval duration (400, 1,300), temporal cuing (valid, invalid), and congruency (congruent, incongruent).

Error percentages were much higher as compared to Experiment 1, such that they could be analyzed by an ANOVA. The main effect of congruency was significant, $F(1, 22) = 17.71$, $p < .001$, leading to less errors on congruent (7%) than on incongruent (13%) trials. The size of this conflict effect differed as a function of the type of conflict (type of Conflict × Congruency: $F(1, 22) = 12.95$, $p = .002$), being larger for Simon (conflict effect: 9%) as compared to spatial Stroop conflict (conflict effect: 3%). Most relevant, the four-way interaction was significant, $F(1, 22) = 7.35$, $p = .01$. Follow-up subsidiary analyses of this interaction confirmed the typical result that temporal cuing is only effective at short intervals. Thus, the interaction between type of conflict, temporal cuing, and congruency was only significant at the short interval, $F(1, 22) = 6.29$, $p = .02$, but not at the long interval, $F(1, 22) = 2.01$, $p = .17$. This significant interaction is displayed in Figure 3 (left), which clearly shows that temporal cuing modulated the conflict effect in opposite directions for Simon conflict and spatial Stroop conflict.

Specifically, the interaction between cuing and congruency was significant for Simon conflict, $F(1, 22) = 5.09$, $p = .03$, and marginally significant for spatial Stroop conflict, $F(1, 22) = 3.08$, $p = .09$. In the Simon condition, specific analysis of the Cuing × Congruency interaction revealed that the conflict effect was increased by valid cuing (congruent vs. incongruent: $F(1, 22) = 13.55$, $p = .001$), in relation to invalid cuing, in which the conflict effect was not significant (congruent vs. incongruent: $F(1, 22) = 1.29$, $p = .27$). Further analyses revealed that the increment of Simon conflict by cuing was driven by interference in the incongruent condition (validity effect: −6%; $F(1, 22) = 4.75$, $p = .04$) rather than by facilitation in the congruent condition (validity effect: 2%; $F < 1$) (see Table 1 for detailed data). In contrast, in the spatial Stroop condition the conflict effect was abolished by valid cuing (congruent vs. incongruent: $F(1, 22) = 1.38$, $p = .25$), as compared to invalid cuing (congruent vs. incongruent: $F(1, 22) = 7.85$, $p = .01$).

The RT analysis showed significant main effects of type of conflict, $F(1, 22) = 13.88$, $p = .001$, interval duration, $F(1, 22) = 7.82$, $p = .01$, and congruency, $F(1, 22) = 28.44$, $p < .001$. Specifically, RTs were faster for Simon versus spatial Stroop conflict, for short versus long intervals, and for congruent versus incongruent trials. The 4-way interaction showed a trend toward significance, $F(1, 22) = 3.12$, $p = .09$. Replicating the error data, the interaction between type of conflict, temporal cuing, and congruency was only significant at the short interval, $F(1, 22) = 5.00$, $p = .036$, but not at the long interval ($F < 1$). This significant interaction is displayed in Figure 3 (right), which shows that RTs mirrored the pattern of error data, thus ruling out a speed-accuracy trade-off. Likewise, temporal cuing modulated the conflict effect in opposite directions for Simon and spatial Stroop conflict.

Figure 3 also shows that the cuing effect was clearest for spatial Stroop conflict, in which the interaction between cuing and congruency was reliable, $F(1, 22) = 7.94$, $p = .01$. Crucially, specific analyses of this interaction revealed that, although the conflict effect was significant in both cases, it

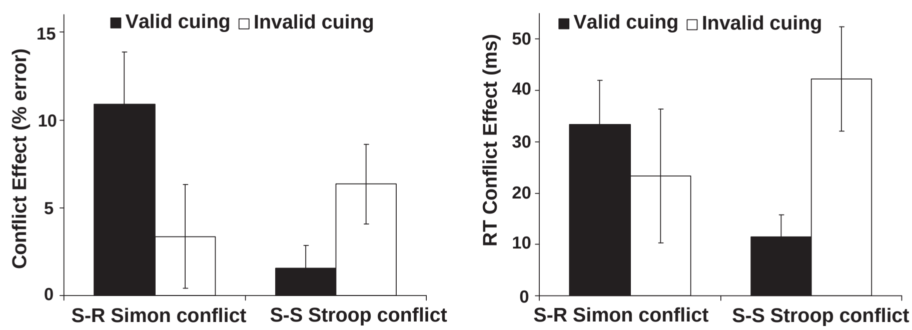

Figure 3. Simon-Stroop task of Experiment 2. The effect of temporal orienting on the resolution of response conflict versus perceptual conflict. Mean conflict effect for error percentages (left panel) and RTs (right panel) are plotted as a function of conflict type (response conflict or S-R Simon, perceptual conflict or S-S spatial Stroop) and temporal cuing (valid, invalid). Only data from the short interval condition are shown in the figure. Vertical bars represent standard errors. Temporal orienting increased response conflict as measured by the Simon condition, whereas it decreased perceptual conflict as measured by the spatial Stroop condition.

was reduced by valid cuing (conflict effect: 12 ms; $F(1, 22) = 7.24$, $p = .01$) in relation to invalid cuing (conflict effect: 42 ms; $F(1, 22) = 17.31$, $p < .001$). Further analyses revealed that the reduction of conflict by cuing was due to facilitation on incongruent (validity effect: 22 ms; $F(1, 22) = 9.79$, $p = .004$) rather than on congruent conditions (validity effect: −8 ms; $F(1, 22) = 1.03$, $p = .32$).

Discussion

Experiment 2 confirmed that temporal orienting influences executive control. Furthermore, the comparison between perceptual and response competition delineated specific conditions under which temporal orienting enhances or interferes with the resolution of conflict. Specifically, the Simon condition of Experiment 2 replicated the findings of the flanker task in Experiment 1, which suggests that temporal orienting impairs the resolution of response conflict. In contrast, the spatial Stroop condition revealed that temporal orienting facilitated the resolution of perceptual conflict. This paradoxical finding suggests that temporal expectations modulate different stages of conflict processing through dissociable mechanisms.

General Discussion

The current study addressed the role of temporal orienting during the controlled selection of stimuli and responses from competing alternatives. Controlled selection was studied with three classical conflict tasks, which placed competition between representations at different levels of processing. The flanker task (Experiment 1) and the Simon condition (Experiment 2) involved response conflict, whereas the spatial Stroop condition (Experiment 2) involved perceptual conflict (Kornblum, Hasbroucq, & Osman, 1990). The results revealed that temporal orienting exerted dissociable modulations of response and perceptual conflict. Paradoxically, temporal orienting impaired the resolution of response conflict, while it facilitated the resolution of perceptual conflict.

Facilitation of perceptual selection confirmed our initial hypothesis and is consistent with spatial orienting research showing smaller spatial Stroop effects for targets appearing at cued versus uncued peripheral spatial locations (Lupiáñez & Funes, 2005). These results extend previous research showing that orienting attention to selective temporal moments can facilitate simple (nonconflicting) perceptual processing (see Nobre, Correa, & Coull, 2007, for a review), by further revealing that temporal orienting also enhances complex perceptual selection of competing stimulus dimensions. The current task parameters (targets appearing very briefly, with spatial uncertainty, and accompanied by competing distractors) may have led to a degraded perceptual representation of the target. Increased activation of target representation by temporal orienting could then facilitate the selection of stimulus features for targets appearing at attended moments.

Although neural modulation by temporal orienting upon perceptual processing is currently well documented (Anderson & Sheinberg, 2008; Correa, Lupiáñez, Madrid, et al., 2006; Doherty et al., 2005; Lange et al., 2003), the mechanism underlying this modulation yet remains unclear. Recent works suggest that perceptual selection could be accomplished through top-down regulation of the temporal properties (phase resetting and frequency – *refresh rate* – increments) of neuronal oscillations in the visual system (Correa, Sanabria, et al., 2006; Schroeder & Lakatos, 2009).

In contrast, the interference with response selection yielded by temporal orienting was unexpected according to previous research showing that temporal orienting enhances response preparation (Correa & Nobre, 2008; Coull & Nobre, 1998; Miniussi et al., 1999; Nobre, 2001). More generally, the current results challenge the common view that attentional preparation optimizes all types of behavioral performance. Indeed, excessively high levels of activation have also been related to poor performance, specially under difficult task conditions (Posner, 1978; Yerkes & Dodson, 1908). Likewise, in the current study, temporal orienting could have overactivated the two competing responses (i.e., correct and incorrect), which typically are activated automatically in response-conflict conditions (e.g., Lu & Proctor, 1995).

According to models of response selection based on activation thresholds (Botvinick et al., 2001), if temporal orienting activates the competing responses above the threshold, then response competition will become stronger, therefore interfering with controlled selection. This account was supported by the findings of both no facilitation (i.e., null cuing effects) on the incongruent flanker condition (Experiment 1) and interference (reversed cuing effects) on the incongruent Simon condition (Experiment 2). Moreover, this account fits well with the finding that temporally predictive warning cues increase the conflict effect in the flanker task (Callejas, Lupiáñez, Funes, & Tudela, 2005).

To conclude, the present study showed that temporal orienting can modulate stimulus processing associated with complex selection of stimuli and responses. Temporal orienting led to paradoxical effects on the resolution of perceptual versus response conflict, which suggests that the two types of conflict manipulated in our tasks rely on different neural pathways. For example, perceptual conflict and response conflict may have involved the "what" and "where" visual pathways, respectively (Mishkin, Ungerleider, & Macko, 1983). Brain research will be necessary to test this hypothesis and to better understand how temporal orienting influences executive control. These research issues may be considered for the design and optimization of computer interfaces assisting human activities that require executive control.

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References

Anderson, B., & Sheinberg, D. L. (2008). Effects of temporal context and temporal expectancy on neural activity in inferior temporal cortex. *Neuropsychologia, 46*(4), 947–957.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108*(3), 624–652.

Callejas, A., Lupiáñez, J., Funes, M. J., & Tudela, P. (2005). Modulations among the alerting, orienting and executive control networks. *Experimental Brain Research, 167*, 27–37.

Correa, Á., Lupiáñez, J., Madrid, E., & Tudela, P. (2006). Temporal attention enhances early visual processing: A review and new evidence from event-related potentials. *Brain Research, 1076*(1), 116–128.

Correa, Á., Lupiáñez, J., & Tudela, P. (2005). Attentional preparation based on temporal expectancy modulates processing at the perceptual-level. *Psychonomic Bulletin and Review, 12*(2), 328–334.

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

Correa, Á., & Nobre, A. C. (2008). Neural modulation by regularity and passage of time. *Journal of Neurophysiology, 100*(3), 1649–1655.

Correa, Á., Sanabria, D., Spence, C., Tudela, P., & Lupiáñez, J. (2006). Selective temporal attention enhances the temporal resolution of visual perception: Evidence from a temporal order judgment task. *Brain Research, 1070*(1), 202–205.

Coull, J. T., Frith, C. D., Buchel, C., & Nobre, A. C. (2000). Orienting attention in time: Behavioural and neuroanatomical distinction between exogenous and endogenous shifts. *Neuropsychologia, 38*(6), 808–819.

Coull, J. T., & 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. *The Journal of Neuroscience, 18*(18), 7426–7435.

Doherty, J. R., Rao, A., Mesulam, M. M., & Nobre, A. C. (2005). Synergistic effect of combined temporal and spatial expectations on visual attention. *The Journal of Neuroscience, 25*, 8259–8266.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception and Psychophysics, 16*, 143–149.

Griffin, I. C., Miniussi, C., & Nobre, A. C. (2002). Multiple mechanisms of selective attention: Differential modulation of stimulus processing by attention to space or time. *Neuropsychologia, 40*, 2325–2340.

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis of stimulus-response compatibility – A model and taxonomy. *Psychological Review, 97*, 253–270.

Lange, K., & Röder, B. (2006). Orienting attention to points in time improves stimulus processing both within and across modalities. *Journal of Cognitive Neuroscience, 18*(5), 715–729.

Lange, K., Rösler, F., & 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*, 806–817.

Liu, X., Banich, M. T., Jacobson, B. L., & Tanabe, J. L. (2004). Common and distinct neural substrates of attentional control in an integrated Simon and spatial Stroop task as assessed by event-related fMRI. *NeuroImage, 22*, 1097–1106.

Lu, C. H., & Proctor, R. W. (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. *Psychonomic Bulletin and Review, 2*(2), 174–207.

Lupiáñez, J., & Funes, M. J. (2005). Peripheral spatial cues modulate spatial congruency effects: Analysing the "locus" of the cueing modulation. *European Journal of Cognitive Psychology, 17*(5), 727–752.

Miniussi, C., Wilding, E. L., Coull, J. T., & Nobre, A. C. (1999). Orienting attention in time: Modulation of brain potentials. *Brain, 122*, 1507–1518.

Mishkin, M., Ungerleider, L. G., & Macko, K. A. (1983). Object vision and spatial vision: Two cortical pathways. *Trends in Neurosciences, 6*, 414–417.

Nobre, A. C. (2001). Orienting attention to instants in time. *Neuropsychologia, 39*, 1317–1328.

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

Posner, M. I. (1978). *Chronometric explorations of mind*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Sanders, L. D., & Astheimer, L. B. (2008). Temporally selective attention modulates early perceptual processing: Event-related potential evidence. *Perception and Psychophysics, 70*(4), 732–742.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-prime user's guide*. Pittsburgh: Psychology Software Tools Inc.

Schroeder, C. E., & Lakatos, P. (2009). Low-frequency neuronal oscillations as instruments of sensory selection. *Trends in Neurosciences, 32*(1), 9–18.

Treccani, B., Cubelli, R., Sala, S. D., & Umilta, C. (2009). Flanker and Simon effects interact at the response selection stage. *Quarterly Journal of Experimental Psychology, 23*, 1–21.

Yeh, Y. Y., & Eriksen, C. W. (1984). Name codes and features in the discrimination of letter forms. *Perception and Psychophysics, 36*, 225–233.

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology, 18*, 459–482.

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