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RESEARCH ARTICLE

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The attentional mechanism of temporal orienting: determinants and attributes

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Abstract A review of traditional research on preparation and foreperiod has identified strategic (endogenous) and automatic (exogenous) factors probably involved in endogenous temporal-orienting experiments, such as the type of task, the way by which temporal expectancy is manipulated, the probability of target occurrence and automatic sequential effects, yet their combined impact had not been investigated. These factors were manipulated within the same temporal-orienting procedure, in which a temporal cue indicated that the target could appear after an interval of either 400 or 1,400 ms. We observed faster reaction times for validly versus invalidly cued targets, that is, endogenous temporal-orienting effects. The main results were that the probability of target occurrence (catch-trial proportion) modulated temporal orienting, such that the attentional effects at the short interval were independent of catch trials, whereas at the long interval the effects were only observed when catch trials were present. In contrast, the interval duration of the previous trial (i.e., exogenous sequential effects) did not influence endogenous temporal orienting. A flexible and endogenous mechanism of attentional orienting in time can account for these results. Despite the contribution of other factors, the use of predictive temporal cues was sufficient to yield attentional facilitation based on temporal expectancy.

Keywords Attention · Time perception · Discrimination · Reaction time · Cognition

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Introduction

The ability to process in advance stimulus attributes that could be relevant for adaptive behavior is a crucial feature of attention. The environment provides implicit and explicit information that can be used to anticipate such attributes. As a result, one can develop preparation, which facilitates subsequent stimulus processing. Preparation is usually divided into processes of unspecific or exogenous preparation (stimulus driven) and specific or endogenous preparation (driven by internal expectancy). The focus of the present work will be the processes of specific preparation.

Early research searched for the time interval at which preparation was optimal, that is, on the amount of time necessary to develop a state of maximal readiness. For instance, Woodrow (1914) presented a warning signal to indicate the impending delivery of a target stimulus and manipulated the length of *foreperiod* or stimulus onset asynchrony (SOA), namely, the time interval between the onsets of the warning signal and target. The shortest reaction times (RTs) to detect the target were observed at foreperiod durations of between 2 and 4 s, suggesting this interval as the optimal foreperiod to reach 'full attention'.

However, later studies observed that the preparation process had not a fixed temporal course, which could be modulated by several factors such as the type of *task* (see Bertelson 1967). Thus, simple-RT tasks led to shorter optimal foreperiods than choice-RT tasks, probably due to the fact that the former afforded more anticipatory responses before the target onset than the latter. More recently, Niemi and Näätänen (1981) made an extensive review of the factors involved in the effects of foreperiod on RT. The between-blocks vs. within-blocks foreperiod manipulation, duration of the preceding foreperiod, probability of stimulus occurrence and frequency of foreperiods of different durations are some factors on which the present work will focus.

The between-blocks vs. within-blocks foreperiod manipulation concerns the way by which foreperiods of different durations are presented in an experiment. [1] In a between-blocks manipulation, different foreperiods are presented in separated blocks of trials. The typical results consist of a lengthening in RTs related to increments in foreperiod duration (e.g., Klemmer 1956). Klemmer suggested that, whereas short constant foreperiods allowed confident and accurate predictions on the temporal onset of the target, at the long foreperiod these predictions were less accurate, i.e., the time uncertainty was higher (see the scalar theory in time perception, Gibbon et al. 1984). On the other hand, in a within-blocks manipulation, different foreperiods are randomly intermixed among trials within the same experimental block. In contrast, the results show that RTs are slower at short foreperiods compared to longer foreperiods (e.g., Woodrow 1914; Klemmer 1956). At short foreperiods, uncertainty regarding the forthcoming foreperiod duration could have impaired the accurate timing of the participants' preparation. At long foreperiods, however, the uncertainty produced by foreperiod variability could be reduced using the information provided by the flow of time itself (Elithorn and Lawrence 1955). Thus, the longer the time for expecting a target, the higher is the probability of its occurrence.

Interestingly, the mixing of trials with different foreperiods led some researchers to investigate *sequential effects*, that is, the effects due to the order of presentation of such foreperiods. Then, the duration of the preceding foreperiod showed to be an important factor that modulated RTs in studies on preparation (e.g., Woodrow 1914). For instance, Granjon and Reynard (1977) found asymmetrical sequential effects, so that RTs were lengthened when the previous foreperiod was longer than the current foreperiod. That is, RTs at a short current foreperiod were slower when the previous foreperiod was long rather than short. This relation was not symmetrical, as RTs at the long current foreperiod were unaffected by the previous foreperiod duration. Hence, sequential effects were also considered to explain the finding of long RTs at short foreperiods in the within-blocks manipulation mentioned above (Klemmer 1956).

Two main accounts are discussed here to explain sequential effects. One possibility is that sequential effects are produced by automatic or exogenous factors, i.e., a sort of inertia or repetition priming between the preceding and the current trial (see also Los and Van den Heuvel 2001, for an explanation based on trace conditioning). In contrast, the strategic or endogenous account of sequential effects considers that participants use the duration of the previous foreperiod to build expectancy concerning the duration of the subsequent foreperiod (e.g., Karlin 1959; Drazin 1961; Niemi and Näätänen 1981). That is, participants anticipate the current foreperiod by expecting a repetition of the previous foreperiod. Then, at the current short foreperiod, RTs are slower when the previous foreperiod was long rather than short, as the target actually appeared earlier than expected (i.e., the participants were "*caught napping*"; Karlin, 1959). At the current long foreperiod, however, RTs are not slower for targets appearing later than expected (i.e., when the previous foreperiod was short rather than long), as a process of repreparation is assumed to occur (e.g., Karlin 1959; Alegria 1975). Repreparation consists of developing an additional state of preparation tuned to a long foreperiod once participants realize that the target failed to appear at the expected short foreperiod. This leads to similar levels of preparation at the current long foreperiod regardless the duration of the previous one. The repreparation hypothesis has been supported by physiological research (Loveless and Sandford 1974). Moreover, as will be described below, recent studies concerning the strategic factors in building temporal expectancy have provided further evidence (see also Coull et al. 2000, for neuroimaging evidence; Correa et al. 2004).

In relation to the probability of stimulus occurrence, Drazin (1961) noted that including a proportion of trials in which the target was not presented (catch trials) could modulate the effects of foreperiod on RT. The use of catch trials in simple-RT experiments is a common practice to minimize the frequency of anticipatory responses. The main result was that increments in the catch trial proportion produced increments in RTs, especially at long foreperiods (Drazin 1961; Näätänen 1972). Näätänen suggested that the subjective probability of the expected target occurrence decreases as the foreperiod becomes longer in a context of a catch trial manipulation, which impairs the participants' preparation (i.e., catch trials induce a kind of '*dispreparation*').

In the final set of studies reviewed here, the relative frequency of foreperiods of different durations was manipulated to explore the effects on RT (Zahn and Rosenthal 1966; Baumeister and Joubert 1969). In these experiments, short and long foreperiods were randomly presented within a block of trials and their relative proportion was changed across different experimental conditions. The most important finding was a significant interaction between foreperiod proportion and foreperiod duration. At the short foreperiod, RTs were faster when the most frequent foreperiod was short rather than long. However, the effect of foreperiod frequency was not significant at the long foreperiod.

Interestingly, the effect at the short foreperiod was interpreted in terms of variations of specific preparation according to temporal expectancy (Zahn and Rosenthal 1966). Thus, a high probability of short foreperiods induced an early expectancy, so that the preparation process was synchronized to the early target onset. On the other hand, the lack of effects at the long foreperiod could be due to a *floor* effect, in which the repreparation process

[1] In the experiments reviewed here, the foreperiod durations usually ranged from 0.5 to 16 s.

was involved. That is, the RT enhancement in the condition of the frequent long foreperiod (late expectancy), was obscured by the RT enhancement in the condition of the frequent short foreperiod due to a repreparation to the long foreperiod (i.e., the original early expectancy was disconfirmed and replaced by a late expectancy).

Moreover, note that sequential effects could also be contributing to the results. In fact, the interaction between foreperiod proportion and foreperiod duration resembled the pattern of data described for asymmetrical sequential effects. However, Zahn and Rosenthal (1966) isolated both sequential and foreperiod probability effects by reanalysing the data, such that the duration of the previous foreperiod was held constant. The authors found main effects of the previous foreperiod and foreperiod probability, but no interaction between the two factors, which led them to assume different mechanisms influencing RT.

Taken together, these studies suggest that several sources of information are used to develop preparation for the target arrival in RT experiments. Thus, participants would be able to reduce uncertainty regarding temporal occurrence of the target by using, more or less explicitly, the available information. For instance, when the target always follows the warning signal after a constant interval (between-blocks manipulations, e.g., Klemmer 1956; Bertelson 1967), or the target appears with a high probability at a given interval (within-block manipulations, Zahn and Rosenthal 1966; Baumeister and Joubert 1969), the time course of preparation can be modulated to match its optimal point with the *inferred* moment of target arrival.

Furthermore, if this probabilistic information were not available, participants could use the interval duration of the previous trial to anticipate the actual target arrival (Karlin 1959; Drazin 1961). If this information were disconfirmed, for example, by a target appearing later than expected, a repreparation process tuned to that later moment could be triggered then (Karlin 1959; Alegria 1975). Finally, the manipulation of the catch-trial proportion also influenced preparation by inducing uncertainty regarding target occurrence. Thus, when participants perceive the target arrival as unlikely in conditions of a high catch-trial proportion, they tend to *relax* their state of preparation (Näätänen 1972).

Although these observations are inferred according to the strategic view of preparation, they can be interpreted according to automatic views (see above, or Los and Van den Heuvel, 2001). This raises a question that cannot be directly addressed by the reviewed studies on foreperiod, that is, whether preparation based on temporal expectancy can be intentionally built. In other words, what if participants were explicitly informed about the time they have to wait for the onset of a relevant event? Could they voluntarily use temporal cues to attend to the moment at which an event is expected to occur? Recently, the studies on endogenous temporal orienting of attention have addressed this question directly.

Studies on endogenous temporal orienting of attention

The temporal orienting of attention refers to the specific preparation based on temporal expectancy, which is built up by using predictive information about time intervals. In other words, it refers to the endogenous ability to selectively attend to a particular time interval. Coull and Nobre (1998) studied temporal orienting using a temporal version of the Posner's spatial cuing procedure (Posner et al. 1980). They presented symbolic cues to indicate with a high probability the temporal interval at which the target was most likely to appear, either '*early*' (after a short interval of 400 ms) or '*late*' (after a long interval of 1,600 ms). The SOA was manipulated, such that the target actually appeared either at the validly cued time interval in 80% of trials (valid trials) or at the uncued interval in the remaining 20% of trials (invalid trials). The participants' task was to detect the target onset as fast and as accurately as possible.

As observed for spatial attention, RTs were faster for targets appearing at expected intervals (valid trials) compared to unexpected time intervals (invalid trials). This validity effect (so-called 'temporal orienting effect') was restricted to the short SOA, such that RTs were faster for the early cue-short SOA condition compared to the late cue-short SOA condition (see also Kingstone 1992). As suggested in studies on foreperiod and preparation (Karlin 1959), the lack of effects at the long SOA was attributed to a process of repreparation (i.e., the reorienting of temporal attention from the invalidly cued short interval to the actual long interval, Coull and Nobre, 1998). The results revealed that participants could modulate the temporal course of preparation according to the temporal expectancy elicited by the cue, at least for a short interval. In contrast, validity effects at the long interval have been rarely observed (but see, Griffin et al. 2001; Milliken et al. 2003).

However, the finding of temporal orienting effects at both short and long intervals would provide more compelling evidence about the flexibility of the attentional orienting mechanism. Then, we conducted a temporal-orienting study (Correa et al. 2004), in which the probability of stimulus occurrence was manipulated by including a catch-trial proportion of .25. The results revealed temporal orienting effects at both the short and long intervals, supporting the flexibility of temporal attention. In particular, validity effects at the long interval were significant only in the group with catch trials. In the group without catch trials, validity effects at the long interval were presumably obscured by the reorienting of attention. We proposed that the uncertainty regarding target occurrence induced by the presence of catch trials produced a dispreparation effect, similar to that reported in foreperiod studies (Näätänen 1972). Thus, the reorienting of attention from short to long intervals was impaired, as the probability of target occurrence decreased with time in the catch trial group.

However, the predicted catch × SOA × cue validity interaction was not significant in this study, which could weaken our conclusions.

From the automatic view of foreperiod sequential effects[2], another fact that could question the endogenous character of temporal orienting was the high similarity between the results of temporal orienting and the results of studies on preparation that manipulated the proportion of different foreperiods (Zahn and Rosenthal 1966). Indeed, both temporal orienting and foreperiod studies have in common the manipulation of intervals with different durations. Thus, many factors found in studies on preparation (e.g., sequential effects) could play an important role in the observed temporal orienting effects, in addition to the role of predictive cues. However, the temporal orienting research had not considered the influence of such factors (e.g., see Nobre 2001, for a review). Then, the automatic view of sequential effects could account for the temporal orienting effects, thus questioning its endogenous nature (Los and Van den Heuvel 2001).

Correa et al. (2004) found that both automatic sequential effects and endogenous cue validity effects co-occurred in a temporal orienting procedure, but they did not interact. When the SOA of the previous trial was included as a factor (SOA_{n-1}), the results revealed significant validity effects regardless the SOA_{n-1} duration (i.e., the SOA_{n-1} × cue validity interaction was far from significance, $F < 1$). This suggests that attention can be endogenously directed to a point in time according to the temporal expectancy induced by predictive cues, independently of any effect produced by the previous trial. However, given that the conclusion was based on a null effect, it is important to further replicate the absence of interaction between SOA_{n-1} and cue validity.

Therefore, the present work further addressed the two mentioned issues concerning the flexible/endogenous functioning of the attentional orienting in time. First, in order to test the flexible nature of temporal orienting we investigated whether validity effects could be observed, not only at a short interval, but also at a long interval. Thus, a more systematic catch-trial manipulation was accomplished by using a broader range of catch-trial proportions than in our previous study (Correa et al. 2004), allowing a finer exploration of the linearity of the reorienting and dispreparation processes (i.e., to explore a gradient effect). Then, we expected to observe a significant interaction between catch-trial percentage, SOA and cue validity, such that validity effects at the long SOA were only observed in the groups with catch trials.

Second, in order to test the endogenous nature of temporal orienting, the potential contribution of 'automatic' sequential effects was isolated by manipulating the duration of the preceding interval (see Note 2). If temporal orienting were not merely due to automatic sequential effects, but to endogenous predictive cues, we should observe a main effect of cue validity and no interaction between SOA_{n-1} and cue validity.

Furthermore, the type of task is another factor common to both temporal orienting and traditional studies on preparation. Previous research has found that temporal orienting effects are larger in less demanding tasks (i.e., simple-RT detection) compared to choice-RT discrimination tasks (see also Correa et al. 2004; Griffin et al. 2001). The size of temporal orienting effects also depends on temporal expectancy manipulation (i.e., within-blocks/between-blocks, Correa et al. 2004). These results have been attributed to the controlled nature of the processes involved in endogenous temporal orienting (see Discussion for a detailed explanation). Therefore, we expected to replicate such effects by observing significant task × cue validity, and expectancy manipulation × cue validity interactions.

In sum, the cue validity, catch-trial percentage, SOA duration of the previous trial, task and expectancy manipulation factors were manipulated within the same procedure to have a comprehensive understanding of the temporal orienting mechanism.

Method

Participants

One hundred and twenty-eight students of psychology took part in the experiment for course credit. All participants gave informed consent prior to their inclusion in the study, which was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. There were 16 groups composed of 8 participants each, given by the factorial combination of the three between participants variables: catch-trial percentage (0, 12.5, 25 and 50% catch trials), task (detection vs. discrimination) and expectancy manipulation (within-blocks vs. between-blocks)[3].

Apparatus and stimuli

The presentation of stimuli and data collection were controlled using MEL software (Schneider 1988). The experiment was run on a PC connected to a 14-in. monitor. All the stimuli were presented at the center of the screen. The fixation point consisted of a "+" symbol. The temporal cue was either a short bar (0.38°×0.95° of visual angle at a viewing distance of 60 cm) or a long bar (0.38°×2.1°). The short bar indicated that the target

[2] Although the strategic view could also account for sequential effects, we will consider here sequential effects as an automatic contribution to temporal orienting effects, in order to further isolate the endogenous contribution of other strategic factors, such as the role of predictive temporal cues.

[3] Data from four groups of the discrimination task (within-blocks and between-blocks groups by the 0 and 25% catch trial groups) were already reported in a previous article (Correa et al. 2004).

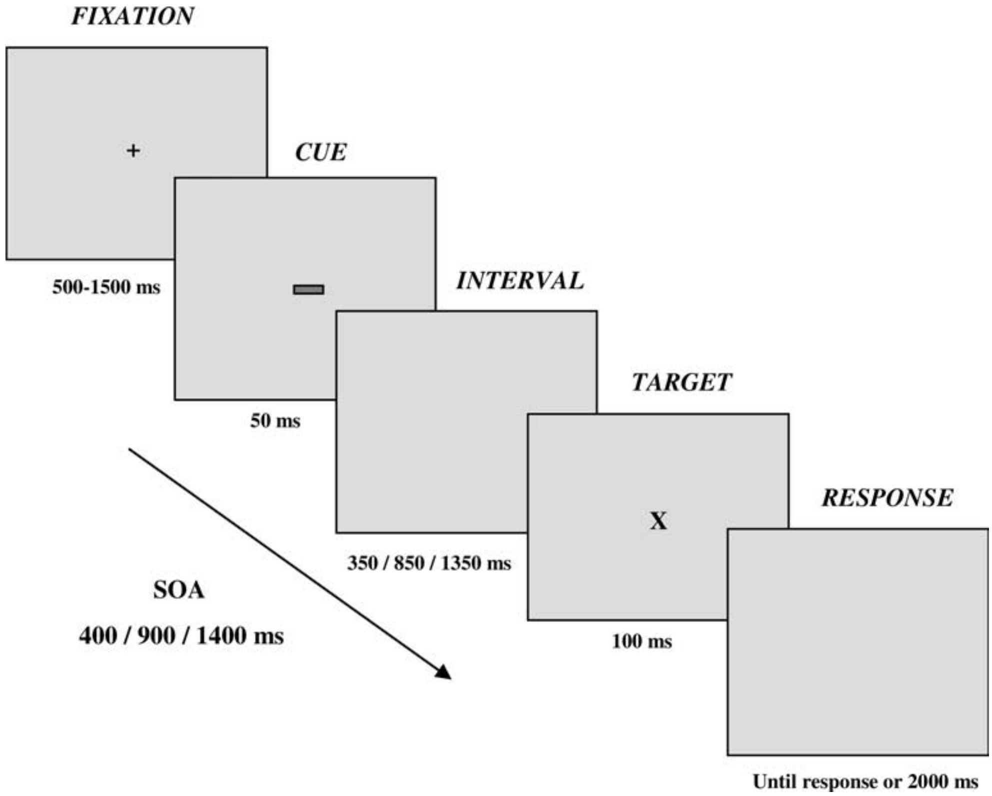

Fig. 1 Sequence of events in a trial

would appear early (after 400 ms). The long bar indicated that the target would appear late (after 1,400 ms). The target was either the letter 'O' or the letter 'X' (0.38°×0.76°). The two target letters appeared with a probability of 0.50. In the detection task groups, the participants pressed the 'B' key when either an 'O' or an 'X' appeared. In the discrimination task groups, participants pressed the 'Z' key for one target and the 'M' key for the other target. The assignment of targets to response keys was counterbalanced across participants within each group.

Procedure

The participants sat approximately 60 cm from the screen. They were instructed to respond as quickly and accurately as possible, and to use the temporal cue to anticipate the moment of target onset. Auditory feedback (a 400-Hz tone of 100 ms) was provided on error trials. The sequence of events in a trial is depicted in Fig. 1. The fixation point was displayed in black on a gray background for a random duration of 500–1,500 ms. The temporal cue appeared for 50 ms. Next, the screen remained blank for a variable delay of 350, 850, or 1,350 ms depending on the SOA for that trial. The target was displayed for 100 ms and was then replaced by a blank screen until the participant made a response. Then, the next trial began. When no response was made, the next trial began after a delay of 2,000 ms.

The experiment consisted of one block of 64 practice trials and four blocks of 128 experimental trials. There was a 1-min interruption for rest at the end of each block. Half of the participants (i.e., the between-blocks group) were presented two experimental blocks with an expect-early cue and two blocks with an expect-late cue. The order of presentation of these blocks was counterbalanced. In the within-blocks group, early cues and late cues were randomly intermixed among trials. Each experimental block consisted of 96 valid trials and 32 invalid trials, resulting in a validity proportion of .75. On half of the valid trials, the cue indicated that the target was likely to appear *early*, and the target appeared at the short SOA (i.e., 400 ms after cue onset). On the remaining half of the valid trials, the cue indicated that the target was likely to appear *late*, and the target appeared at the long SOA (i.e., 1,400 ms after cue onset). The invalid trials were also equally distributed between SOAs. Thus, all the trials at the medium SOA (850 ms) were invalid.[4]. The groups with catch trials comprised a proportion of trials in which the target was not presented (i.e., 16, 32 and 64 trials for the 12.5, 25

[4]The medium SOA data were not included in the analyses due to insufficient observations in some experimental conditions (e.g., in the 50% catch trials group). The medium SOA has been previously used to make trend analyses in the RT function, in order to explore whether the attentional resources are assigned to specific moments in time in a gradual manner. Hence, the medium SOA did not provide relevant information for the purposes of the present study.

and 50% catch trials groups, respectively), holding constant the valid/invalid trial ratio to 3:1.

Results

Trials with correct responses faster than 100 ms (1.89%) or slower than 1,000 ms (1.07%), incorrect discrimination responses (3.52%), and the first trial of each block were excluded from the RT analyses. Table 1 shows the mean RTs for each experimental condition.

Mean RTs were submitted to a mixed factor analysis of variance (ANOVA) with SOA (short/long) and cue validity (valid/invalid) as within-subjects variables, and task (detection/discrimination), expectancy manipulation (between-blocks/within-blocks) and catch-trial percentage (0/12.5/25/50) as between-subjects variables.

The main effect of task was significant, $F(1, 112) = 143.69$; $P < 0.001$, revealing faster RTs for the detection task compared to the discrimination task. The increase of catch-trial percentage (also referred to as 'catch') progressively lengthened RTs, $F(3, 112) = 10.64$; $P < 0.001$, following a linear trend ($P < 0.001$) rather than a quadratic trend ($P = 0.14$). The main effect of SOA showed faster RTs at the short SOA compared to the long SOA, $F(1, 112) = 7.85$; $P < 0.01$. Importantly, a significant effect of cue validity showed that valid trials yielded faster RTs than invalid trials, $F(1, 112) = 233.88$; $P < 0.001$.

The interaction between task and cue validity was marginally significant, $F(1, 112) = 3.36$; $P = 0.07$, suggesting larger validity effects in the detection task (34 ms; $P < 0.001$) relative to the discrimination task (27 ms; $P < 0.001$). The interaction between expectancy manipulation and cue validity was significant, $F(1, 112) = 67.6$; $P < 0.001$, such that validity effects were larger in the between-blocks groups (46 ms; $P < 0.001$) compared to the within-blocks groups (14 ms; $P < 0.001$). The significant interaction between catch and SOA (see Fig. 2), $F(3, 112) = 33.14$; $P < 0.001$, revealed that in the condition without catch trials (0%), RTs at the long SOA were faster than at the short SOA ($P < 0.001$; i.e., the reorienting effect). In contrast, the conditions with catch trials (12.5, 25 and 50%) showed that RTs at the long SOA increased with increments in catch-trial proportion (all $Ps < 0.02$; i.e., the dispreparation effect).

The interaction between SOA and cue validity, $F(1, 112) = 25.19$; $P < 0.001$, showed larger validity effects at the short SOA (42 ms, $P < 0.001$) than at the long SOA (18 ms, $P < 0.001$). Interestingly, this SOA × cue validity interaction was modulated by catch-trial percentage, $F(3, 112) = 6.91$; $P < 0.001$. Figure 2 depicts the effect of catch-trial percentage on RT as a function of SOA and cue validity. According to our predictions, the catch × SOA × cue validity interaction was further analyzed by focusing on the validity effects at the long SOA within each catch-trial condition. The analyses revealed that the 0% catch-trial was the only condition that did not show validity effects at the long SOA ($P < 0.17$). In contrast, the 12.5, 25 and 50% catch-trial conditions all showed significant validity effects at the long SOA (all $Ps < 0.01$). Also, we further compared the validity effects at the long SOA across catch-trial conditions and the effects were not significantly different between the three conditions with catch trials ($P = 0.4$). Importantly, however, the effects in the three conditions with catch trials were significantly different from the condition without catch trials ($P < 0.04$). Moreover, the analyses of validity effects at the short SOA were significant in all the four catch-trials conditions (all $Ps < 0.001$).

Other three-way interactions (that were less relevant to the main point here) were significant for task × catch × SOA, $F(3, 112) = 2.84$; $P < 0.05$, suggesting that the reorienting effect, as indexed by the catch × SOA interaction (see above), was more pronounced in the detection task, $F(3, 56) = 20.35$; $P < 0.001$, than in the discrimination task, $F(3, 56) = 13.40$; $P < 0.001$. Moreover, the effect of blocking expectancy on validity

Table 1 Mean correct response times (in ms) for catch-trial (%), task and expectancy manipulation as between-subjects variables, and for SOA and cue validity as within-subjects variables

Catch-trial (%)	Task	Expectancy manipulation	Short SOA		Long SOA	
			Valid	Invalid	Valid	Invalid
0	Detection	Within-blocks	350	396	337	340
		Between-blocks	350	447	333	350
	Discrimination	Within-blocks	457	470	449	455
		Between-blocks	455	546	471	477
12.5	Detection	Within-blocks	365	393	390	395
		Between-blocks	368	456	382	428
	Discrimination	Within-blocks	496	498	506	513
		Between-blocks	508	573	552	578
25	Detection	Within-blocks	428	431	453	464
		Between-blocks	367	426	405	426
	Discrimination	Within-blocks	503	520	521	530
		Between-blocks	454	520	498	525
50	Detection	Within-blocks	406	415	416	450
		Between-blocks	409	457	452	480
	Discrimination	Within-blocks	533	551	547	561
		Between-blocks	497	516	522	561

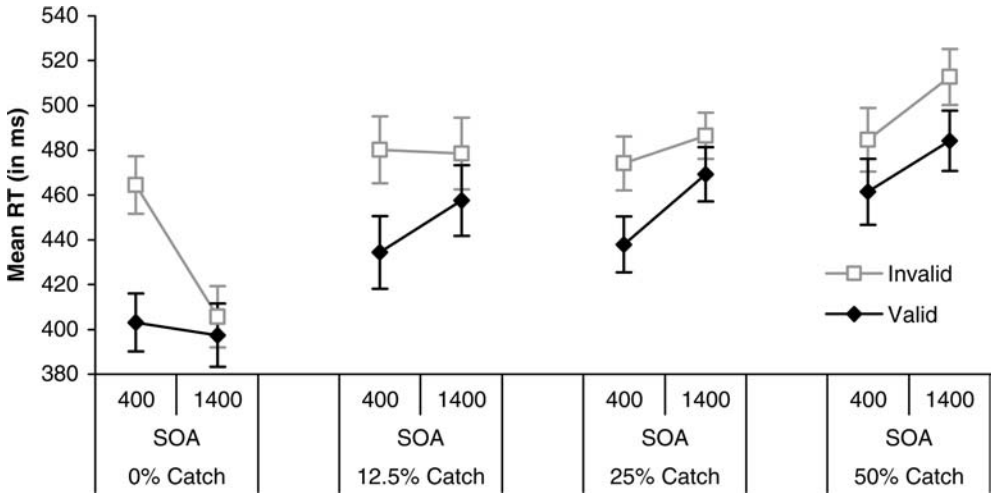

Fig. 2 Mean RTs as a function of catch-trial percentage, SOA and cue validity. The vertical *bars* represent the standard error of the mean

effects, as revealed by the expectancy manipulation × cue validity interaction, depended on catch-trial percentage, $F(3, 112) = 2.75$; $P < 0.05$, such that the interaction was significant in the 0, 12.5 and 25% catch-trial conditions (all $Ps < 0.001$), but marginally significant in the 50% catch-trial condition ($P = 0.07$). Thus, the effect of blocking expectancy on validity effects seemed to be attenuated when catch trials were extremely frequent. This expectancy manipulation × cue validity effect also depended on the SOA, $F(1, 112) = 14.23$; $P < 0.001$, showing that the effect seemed more pronounced at the short SOA, $P < 0.01$, than at the long SOA, $P < 0.001$ (see Table 1 for further details).

The overall accuracy in the discrimination task was of 97.2%. A similar ANOVA to that preformed on RTs was performed on accuracy data. The only difference was that the detection task groups were not included, as they lacked incorrect discrimination responses. The main effect of SOA, $F(1, 56) = 6.38$; $P < 0.01$, was the only significant effect, revealing that discrimination responses were more accurate at the short SOA than at the long SOA.

Sequential effects analysis

The analysis of sequential effects consisted of a repeated-measures ANOVA with SOA_{n-1} (short/long/catch trial), SOA (short/long) and cue validity (valid/invalid) as variables. Given that the addition of the SOA_{n-1} factor multiplies by three the number of experimental conditions of the previous analysis (leading to a quite smaller amount of trials per condition), the between-subjects factors were not included in the analysis, in order to simplify the design[5], and only test the effects for which we had a priori hypotheses. Then, the relevant analysis here focused on the effect of the previous SOA duration on temporal orienting. Data from the 0% catch-trial group were not included, given that this group lacked the SOA_{n-1} - catch trial condition.

The main effect of SOA_{n-1} was significant, $F(2, 154) = 27.25$; $P < 0.001$, yielding the fastest RTs when the previous SOA was short and the slowest RTs when the previous trial was a catch trial. Replicating the analysis above, the main effects of both SOA and cue validity, and the SOA × cue validity interaction were significant, $F(1, 77) = 23.31$; $P < 0.001$, $F(1, 77) = 68.57$; $P < 0.001$ and $F(1, 77) = 4.87$; $P < 0.05$, respectively.

The interaction between SOA_{n-1} and SOA revealed sequential effects, $F(2, 154) = 17.24$; $P < 0.001$ (see Fig. 3). At the short current SOA, RTs were faster when the SOA_{n-1} was short either compared to the long SOA_{n-1} ($P < 0.001$) or the catch-SOA_{n-1} ($P < 0.001$). In contrast, the effect reversed at the long current SOA, such that RTs were faster when the SOA_{n-1} was long either compared to the short SOA_{n-1} ($P < 0.05$) or the catch-SOA_{n-1} ($P < 0.001$).

More importantly for present purposes was that the SOA_{n-1} × cue validity and SOA_{n-1} × SOA × cue validity interactions were far from significance ($F = 0.17$ and $F = 0.58$). As can be seen in Fig. 3, validity effects were significant independently of the previous SOA.

Discussion

The basic finding of a robust effect of *cue validity* suggests that participants can enhance RT performance by attending to the relevant moment indicated by a temporal cue. However, in most of the temporal orienting research, this effect had not been consistently observed to co-occur for intervals of several durations, which questioned the flexible character of temporal orienting. The lack of validity effects at long intervals has been attributed to a reorienting process (Coull and Nobre 1998). This process is engaged when participants realize

[5]The manipulation of the between-subjects factors (e.g., the task) did not reverse the cue validity effects, rather it modulated the size of the effect (see results above, and also Correa et al. 2004). Thus, the analysis by combining the groups did not qualitatively change the main results.

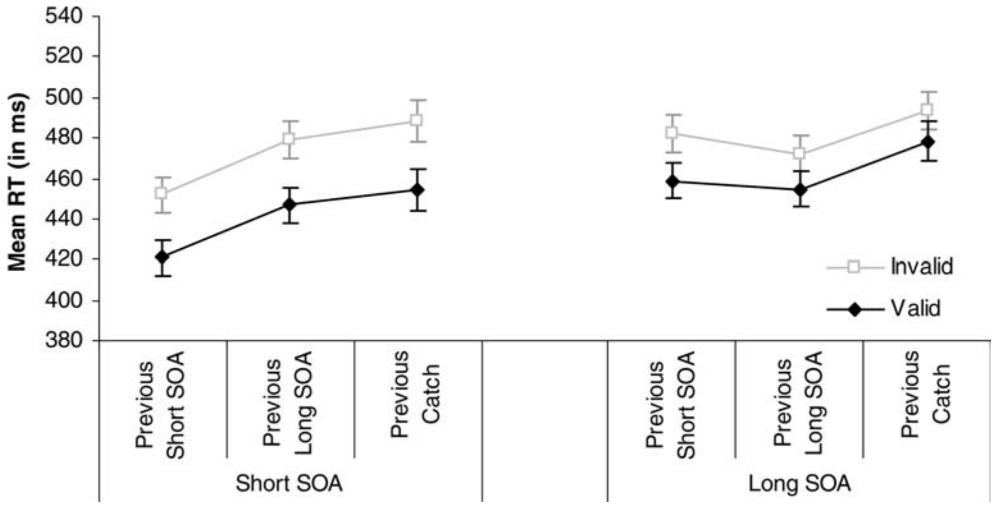

Fig. 3 Mean RTs as a function of the SOA of the previous trial, the current SOA and cue validity. The *vertical bars* represent the standard error of the mean

that the target did not appear at the early cued interval, so that they reorient their attention to a later interval. Then, participants are similarly prepared for a late target onset regardless of the fact whether the cue was early or late.

Despite the physiological evidence supporting the reorienting of attention (Coull et al. 2000; Loveless and Sandford 1974), this process had not been directly manipulated to study its influence on temporal orienting. Note that reorienting makes sense only when the certainty about target occurrence is high. In order to test this hypothesis, we manipulated the reorienting process by varying the probability of target occurrence. Our prediction was that the inclusion of catch trials would impair reorienting, in such a way that validity effects would then be observed at the long SOA. Previous experiments somehow supported this idea (e.g., Milliken et al. 2003), although without statistical significance (Correa et al. 2004).

In the experiment reported here, the systematic manipulation of catch trials percentage revealed for the first time a significant interaction between catch-trial percentage, cue validity and SOA, which further supported the reorienting hypothesis. The catch × SOA interaction showed that RTs increased at the long SOA with higher catch-trial proportions (see Fig. 2). Importantly, just the groups with catch trials (12.5, 25 and 50%) showed significant validity effects at the long SOA, although such effects did not increase gradually with increments in the catch-trial proportion. In contrast, the 0% catch-trial condition showed faster RTs at the long SOA compared to the short SOA, presumably due to the reorienting process, and this was the only condition that did not show validity effects at the long SOA. Therefore, we propose that the target-occurrence uncertainty induced by catch trials produce a dispreparation that impairs reorienting, as deduced by the RT increments at the long SOA. The present findings suggest that dispreparation seems to be an 'all or none' rather than a linear process, so that the mere presence of a small percentage of catch trials (12.5%) is sufficient to trigger dispreparation. According to the strategic view of studies on foreperiod, the state of preparation was weakened as the subjective probability of the expected target occurrence decreased at long foreperiods in a context of catch trials (Näätänen 1972). In sum, the inclusion of catch trials afforded the observation of temporal orienting effects at the long SOA, as well as at the short SOA, which further supports the flexibility of the attentional mechanism involved.

The marginal effect of *task* on temporal orienting was in line with previous research (Correa et al. 2004; Correa et al. 2005), in which validity effects were smaller for discrimination than for detection tasks. This result was attributed to the fact that endogenous temporal orienting involves controlled processing (e.g., underlying processes of time perception, see Brown 1985), and that the demands to maintain in working memory the task-set are higher for the discrimination task (i.e., an arbitrary mapping between stimuli and responses) than for the detection task. Thus, the increment in central resources demands engaged by the discrimination task could difficult the building up of temporal expectancy.

However, a robust interaction between task and cue validity is not easy to be observed, as temporal orienting effects are normally significant for both tasks (e.g., Correa et al. 2005). Future research either including within-subjects manipulations of the task, or manipulating the working memory load within the same task might provide more consistent evidence to this hypothesis. In any case, the finding of significant effects in both tasks is interesting per se, as implies a general mechanism of attentional orienting that is not constrained to a particular task.

As previously reported, the effect of blocking expectancy increased the size of temporal orienting effects (Correa et al. 2004). This result is also consistent with an explanation based on the demands of attentional resources. In between-blocks groups, the continuous building of temporal expectancy for each new trial was unnecessary, given that it remained constant across a block of trials. In contrast, the variations of temporal expectancy in the within-blocks manipulation increased the attentional demands, leading to hindered temporal orienting effects. Converging evidence can be found in other studies that combined demanding discrimination tasks either with a between-blocks manipulation (Correa et al. submitted) or a between-subjects manipulation (Milliken et al. 2003) and reported unusually large validity effects.

The manipulation of the SOA_{n-1} *duration* was critical to disentangle endogenous temporal orienting (elicited by predictive cues) from automatic sequential effects (produced by the duration of the preceding interval). The results showed the typical pattern of sequential effects, as revealed by the interaction between SOA_{n-1} and SOA, and the typical pattern of endogenous temporal orienting, as revealed by the main effect of cue validity (see Fig. 3). Crucially, the $SOA_{n-1} \times$ cue validity and the $SOA_{n-1} \times SOA \times$ cue validity interactions were far from significance ($Fs < 1$), suggesting that sequential effects and temporal orienting trigger independent processes. As can be seen in Fig. 3, RTs were faster for valid vs. invalid cues, and this validity effect was observed either when the previous trial was a short SOA, a long SOA or a catch trial. This finding further replicates previous research, in which the $SOA_{n-1} \times$ cue validity interaction was also far from significance (Correa et al. 2004). Importantly, this null interaction was observed even with the higher statistical power of the present study. Similarly, Zahn and Rosenthal (1966) reported main effects of both the previous foreperiod factor and the foreperiod probability factor, but no interaction between them. Taken together, the results suggest that predictive cues can be used to intentionally modulate the temporal course of preparation in order to achieve a matching with the expected relevant moment, regardless the automatic contribution of sequential effects.

As a general conclusion, the present work has provided an essential link between the research on endogenous temporal orienting and the traditional research on foreperiod and preparation. Several factors that showed to modulate the preparation process in RT experiments, and other factors that were found to influence temporal orienting effects in previous research (Correa et al. 2004; Correa et al. 2005; Griffin et al. 2001; Milliken et al. 2003), were included within the same temporal-orienting procedure in order to obtain a more complete picture of the temporal orienting phenomenon.

The reviewed studies and the results reported here suggest that a predictive temporal cue is not the only source of information that people use to build expectancy, that is, to anticipate the critical moment of the onset of a relevant event. Rather, people are sensitive to several contingencies, more or less explicit, which are inherent to the context of a temporal orienting experiment. For instance, some of the factors involved concern the time certainty regarding target onset in designs with constant foreperiods (Bertelson 1967; Klemmer 1956); the information provided by the flow of time itself (Elithorn and Lawrence 1955); the temporal information provided by the duration of the time interval of the previous trial, according to the strategic view (Karlin 1959; Drazin 1961; Niemi and Näätänen 1981) or the exogenous influence of sequential effects, according to the automatic view (Los and Van den Heuvel 2001); and the probability of stimulus occurrence (Drazin 1961; Näätänen 1972).

Additional factors, such as the task demands and the way in which temporal expectancy was manipulated in the experimental blocks, modulated the process of preparation mainly determining the size of temporal orienting effects. We propose that these two factors determine the amount of central resources available to control the endogenous process of preparation. Thus, in a highly demanding context, the ability to gain attentional benefits by attending to a particular point in time seems hindered. It could be that not only the processes of building and maintaining temporal expectancy in working memory became impaired (Correa et al. 2004), but also the time estimation processes necessary for temporal orienting could suffer from higher inaccuracy in highly demanding conditions (Brown 1985).

To summarize, we conclude that the attentional mechanism by which people can anticipate and control their preparation for a critical moment depends on several factors that determine its functioning. The crucial strategic factor we have found is the predictive value of a temporal cue. That is, the effectiveness of the cue to endogenously induce confident temporal expectancies about the future occurrence of stimuli, allows the strategic development of states of optimal preparation synchronized to the most probable moment of occurrence of the stimuli. As suggested by the results, the use of predictive temporal cues is sufficient per se to yield attentional facilitation on behavioral performance.

The probability of stimulus occurrence is, however, also a determining factor of the temporal orienting mechanism. The first main finding, showing that the catch-trial proportion modulated endogenous temporal orienting, suggests that people consider this probabilistic information to strategically develop the preparation most appropriate to the specific situation. For instance, when participants have the confident prediction that the stimulus will occur, sooner or later, the relevance of being prepared is sufficiently high to engage a reorienting process in case the initial early expectancy was disconfirmed. In contrast, when participants notice that the stimulus do not always occur (i.e., in the context of catch trials), their overall level of preparation decreases with lower *a priori* probabilities of stimulus occurrence. Furthermore, the dynamic process of preparation triggered in a specific trial decreases as the time without stimulus arrival increases (i.e., the dispreparation process), according to the fact that the conditional probability of occurrence decreases with time in the catch-trial conditions. Thus, the systematic manipulation of the catch-trial proportion has uncovered some neglected aspects in temporal orienting research regarding the functioning of the reorienting and dispreparation processes.

The second important factor investigated in the present research is the contribution of sequential effects to temporal orienting. The sequential effects produced by the duration of the preceding interval also influence the dynamic process of preparation in a current trial. However, such effects can be dissociated from the strategic preparation based on predictive temporal cues, which suggests the independence of these two processes involved in preparation. In fact, some authors consider the preparation triggered by sequential effects as unspecific, that is, an exogenous process driven by the stimulus (Los and Van den Heuvel 2001).

The distinction between exogenous and endogenous attention is classical from the very origin of research on attention (James 1890). More recently, studies on spatial orienting of attention have isolated specific features for both exogenous and endogenous mechanisms to commit attention to particular locations in space (e.g., Müller and Rabbitt 1989). Analogously, it makes sense to assume exogenous and endogenous ways to commit attention to particular instants in time (see Coull et al. 2000 for a different approach). This assumption accounts well for the present findings, such that sequential effects trigger exogenous preparation whereas predictive temporal cues trigger endogenous preparation. Then, a logical corollary that can be deduced is that factors that impair endogenous preparation should not necessarily affect exogenous preparation. Indeed, a further analysis revealed that the task and blocking temporal expectancy factors, which modulated endogenous preparation, had no effect on exogenous preparation produced by sequential effects ($P=0.16$ and $F<1$, respectively). Thus, the demands on central processing impaired endogenous temporal orienting effects rather than exogenous sequential effects.

Certainly, there are other ways to exogenously induce temporal preparation, such as the induction of visual rhythms by presenting objects moving at a constant pace (Doherty et al. 2005; Correa and Nobre in preparation) or the induction of auditory rhythms by presenting sounds at regular frequencies (Jones et al. 2002). A challenging research issue for the future could be to specify the characteristics of exogenous and endogenous temporal preparation and to compare them to those of exogenous and endogenous spatial attention.

Concerning the neural basis of the temporal orienting mechanism, neuroimaging studies have revealed a frontoparietal network of areas lateralized to the left hemisphere, including the inferior parietal and premotor cortices (Coull and Nobre 1998; Coull et al. 2000). Moreover, event-related potential studies have found a negative electrophysiological component which is related to the intention of being prepared for an impending stimulus, that is, the contingent negative variation (CNV, Walter et al. 1964). Interestingly, recent electrophysiological research shows that the temporal course of the CNV component can be flexibly modulated according to the temporal expectancies induced by predictive cues (Miniussi et al. 1999; Griffin et al. 2002; Correa et al. submitted), so that the point of maximal preparation (as indexed by the CNV) is time-locked to the expected stimulus onset. This result provides a clear link between this electrophysiological component and the preparation process concerned here. Once identified the key brain correlates of preparation, it would be interesting to explore whether different neural mechanisms underlie the dissociation we have established between exogenous and endogenous preparation.

To conclude, the present work has dissociated exogenous and endogenous factors involved in temporal orienting. The manipulation of such factors has revealed relevant attributes of this attentional mechanism, such as the flexible, strategic and controlled nature of the temporal orienting processes. Moreover, this work has specified suitable experimental conditions to observe robust temporal orienting effects in future research. Finally, the finding of several sources of temporal predictability has implications for RT experiments, especially for those in which the time interval between two stimuli is manipulated.

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