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Dissociating temporal preparation processes as a function of the inter-trial interval duration

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ABSTRACT

Preparation over time is a ubiquitous capacity which implies decreasing uncertainty about when critical events will occur. This capacity is usually studied with the variable foreperiod paradigm, which consists in the random variation of the time interval (foreperiod) between a warning stimulus and a target. With this paradigm, response time (RT) effects of the current and preceding foreperiods are usually observed (respectively called "foreperiod effect" and "sequential effects"). Both single-process trace conditioning mechanisms and dual-process accounts have been proposed to explain these behavioral effects. This study aimed at understanding how manipulations of the inter-trial interval (ITI: 1 s vs. 20 s) and the task context (simple vs. choice RT task) affects the two behavioral effects. Results show that, regardless of the type of RT task, attenuated sequential effects were observed with the longer ITI, contrary to predictions derived from the trace conditioning literature. However, the influence that the ITI duration exerted on the FP effect critically depended on the task context, since the FP effect increased as a function of ITI with a choice RT task but decreased with a simple RT task. These findings support a dissociation between foreperiod and sequential effects, consistent with a dual-process account.

1. Introduction

Temporal preparation is the ability to pre-activate the perceptual and motor systems to an event by predicting its future occurrence (e.g., Bausenhart, Rolke, Hackley, & Ulrich, 2006; Hackley, Schankin, Wohlschlaeger, & Wascher, 2007). Temporal preparation can be initiated by following an explicit temporal cue or, more implicitly, by monitoring elapsing time. The latter is an important capacity in everyday life, whether it concerns a hunter trying to trap its quarry, a sprinter trying to predict the sound of a starting pistol, or a driver waiting for the green traffic light.

In experimental psychology, implicit temporal preparation has been extensively studied by means of the foreperiod (FP) paradigm (Bertelson & Boons, 1960; Los & van den Heuvel, 2001; Niemi & Näätänen, 1981; Steinborn & Langner, 2011; Vallesi & Shallice, 2007; Woodrow, 1914). In this paradigm, a warning stimulus of any modality is followed by a target stimulus after a preparatory interval, called FP. When the FP varies randomly and equiprobably across trials, two behavioral effects usually emerge. Responses are faster for current longer FPs (variable FP effect), and they are slower for longer preceding FPs, especially for current short FPs (asymmetric sequential effects). These effects have been observed for different FP averages and ranges (Niemi & Näätänen, 1981), and for both simple and choice response time (RT) tasks (Correa, Lupiáñez, Milliken, & Tudela, 2004; Karlin, 1959; Simon & Slaviero, 1975; Steinborn, Rolke, Bratzke, & Ulrich, 2009; Vallesi, Shallice, & Walsh, 2007).

Despite the robustness of these empirical findings, the exact underlying cognitive processes are still a matter of

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debate. According to many authors, the variable FP effect originates from a monitoring process, which continuously checks the increasing conditional probability of stimulus occurrence during the FP to optimize behavior (Cui, Stetson, Montague, & Eagleman, 2009; Elithorn & Lawrence, 1955; Gottsdanker, 1984; Näätänen & Merisalo, 1977; Stuss et al., 2005; Vallesi, 2010; Vallesi & Shallice, 2007). This probability is highest for the longest FPs, thus explaining the maximum RT benefit in this condition, provided that there are no catch trials (Correa et al., 2004). The use of catch trials, where no target is presented at all, would indeed decrease the conditional probability of target onset for the longest FPs (which would usually be 100% without catch trials) proportionally to their frequency of occurrence.

Recently, a single-process account has been put forward to explain both the variable FP effect and the sequential effects (Los & van den Heuvel, 2001). On this account, the FP effect is caused by the trace conditioning mechanisms underlying sequential effects. One conditioning mechanism consists of extinction of response preparation associated to short FPs, which takes place when these short FPs are overcome by longer ones during the course of the trial. This is probably due to the demanding and aversive need to keep the motor system in check to avoid anticipatory responses (e.g., Näätänen, 1971), especially in the presence of warning signals (Boulinguez, Ballanger, Granjon, & Benraiss, 2009). Another conditioning mechanism is represented by the reinforcement of response preparation associated to the specific FP which occurs in a given trial. Thus, on this account, sequential effects originate from the interplay between extinction and reinforcement of preparation associated to the different FPs. Since the longest FPs cannot be overcome by even longer ones, the preparation level associated to them is only reinforced (when they occur), thus also explaining the RT advantage for long FPs (i.e., the variable FP effect).

Additional empirical evidence suggests that the FP and the sequential effects are due to at least partially different underlying neural and cognitive mechanisms, as it has been demonstrated by life-span (Vallesi, McIntosh, & Stuss, 2009; Vallesi & Shallice, 2007), neuroimaging (Vallesi, McIntosh, Shallice, & Stuss, 2009), TMS (Vallesi et al., 2007) and neuropsychological (Stuss et al., 2005; Triviño, Correa, Arnedo, & Lupiáñez, 2010; Vallesi & Mussoni et al., 2007) dissociations. This multimodal evidence shows that the monitoring process, which is traditionally thought as responsible for the variable FP effect (cf., Los & van den Heuvel, 2001), usually recruits the right dorsolateral prefrontal cortex (Stuss et al., 2005; Triviño et al., 2010; Vallesi et al., 2007).

On the other hand, traditional strategic explanations of the sequential effects (e.g., Alegria, 1975; Granjon & Reynard, 1977) seem to be inappropriate because, although sequential effects vanish with valid temporal cues, they strongly re-emerge with invalid ones, when strategic processes are unlikely to occur (Los & van den Heuvel, 2001). The foreperiod and sequential effects are also dissociable in terms of their anatomical locus. Indeed, while lesions to right frontal regions cause a reduction of the FP effect (Stuss et al., 2005; Vallesi & Mussoni et al., 2007), lesions to left premotor regions are accompanied by a disappearance of the sequential effects (Vallesi & Mussoni et al., 2007). In particular, left premotor patients do not show the RT advantage for short-short FP sequences, despite a normal FP effect.

Based on these findings, a dual-process account was put forward (Vallesi, 2010; Vallesi & Shallice, 2007; Vallesi et al., 2007). This account states that sequential effects are due to tonic arousal modulations deriving from the preparation duration on the previous trial. This assumption is motivated by evidence from developmental data. While adults usually do not show errors in this simple behavioral paradigm, 4 and 5 years old children show both anticipations during the FP and very slow or null responses (Vallesi & Shallice, 2007). These two types of errors are particularly revealing, since they were not evenly distributed across conditions. On the one hand, anticipations occurred more often after preceding short FPs, suggesting facilitatory mechanisms on motor arousal (also see Vallesi et al., 2007). On the other hand, delayed and null responses were more frequent after long preceding FPs, compatible with a temporary refractory period at the motor arousal level. This motor refractoriness is supposed to be proportional to the preparation time (FP length) in the previous trial.

Since sequential effects are produced and sustained mainly by non-strategic processes originating from the previous trial (e.g., Los & van den Heuvel, 2001; Vallesi & Shallice, 2007), it is conceivable that, on the dual-process account (Vallesi & Shallice, 2007; Vallesi et al., 2007), the underlying motor arousal modulation is temporary in nature and decays with more spacing between trials. Thus, increasing the length of the resting time between trials (i.e., inter-trial interval, ITI) is expected to bring arousal levels closer to baseline values. Specifically, if RT facilitation of short-short FP sequences is time-sensitive, this facilitation effect should be reduced with long vs. short ITIs. Moreover, if refractoriness after a trial with a long FP recovers over time, RTs in long-short FP sequences would be shorter for long vs. short ITIs. In summary, both facilitation and refractory effects should decrease with long ITIs and, consequently, sequential effects should either diminish or disappear.

On the other hand, the dual-process account explains the variable FP effect through a strategic monitoring process which, starting from the onset of the warning stimulus, continuously checks the increasing conditional probability of target occurrence over time to optimize behavior (Vallesi et al., 2007; Vallesi, McIntosh, Shallice, & Stuss, 2009; also see Elithorn & Lawrence, 1955; Näätänen, 1970). Considering monitoring as an effortful, resource consuming process, a long resting period (ITI) between trials should allow participants to be more prepared to respond to a target. Consequently, a greater FP effect (shorter RTs for longer FPs than for shorter ones) should emerge with a long ITI than with a short one. Critically, if the FP effect originates from a monitoring mechanism different from the mechanism underlying sequential effects (cf., Los & van den Heuvel, 2001), its modulation by ITI duration should be independent of the ITI influence on the sequential effects.