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Sequential effects within a short foreperiod context: Evidence for the conditioning account of temporal preparation

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ABSTRACT

Responses to an imperative stimulus (IS) are especially fast when they are preceded by a warning signal (WS). When the interval between WS and IS (the foreperiod, FP) is variable, reaction time (RT) is not only influenced by the current FP but also by the FP of the preceding trial. These sequential effects have recently been proposed to originate from a trace conditioning process, in which the individuals learn the temporal WS–IS relationship in a trial-by-trial manner. Research has shown that trace conditioning is maximal when the temporal interval between the conditioned and unconditioned stimulus is between 0.25 and 0.60 s. Consequently, one would predict that sequential effects occur especially within short FP contexts. However, this prediction is contradicted by Karlin [Karlin, L. (1959). Reaction time as a function of foreperiod duration and variability. *Journal of Experimental Psychology, 58*, 185–191] who did not observe the typical sequential effects with short FPs. To investigate temporal preparation for short FPs, three experiments were conducted, examining the sequential FP effect comparably for short and long FP-sets (Experiment 1), assessing the influence of catch trials (Experiment 2) and the case of a very dense FP-range (Experiment 3) on sequential FP effects. The results provide strong evidence for sequential effects within a short FP context and thus support the trace conditioning account of temporal preparation.

1. Introduction

In reaction time (RT) tasks, a warning signal (WS) typically precedes the imperative response stimulus (IS). Since the pioneering work of Woodrow (1914), it has been repeatedly shown that RT is strongly influenced by the interval between the WS and the IS, that is, by the foreperiod (FP, Niemi & Näätänen, 1981, for a review). This FP effect depends on whether the FP duration varies randomly from trial-to-trial (variable FP condition) or remains constant within a block of trials and only varies across blocks (constant FP condition). In the constant condition, mean RT usually increases progressively as the FP duration is increased. In the variable condition, however, mean RT usually decreases as the FP duration increases. These two FP effects are well-established and they can be observed for both simple and choice RT tasks (Bertelson & Boons, 1960; Mattes & Ulrich, 1997; Sanders, 1998, p. 173). Since the WS conveys no information about the response, these effects reflect a state of non-specific preparation, sometimes referred to as temporal preparation (Müller-Gethmann, Ulrich, & Rinkenauer, 2003; Rolke & Hofmann, 2007).

The traditional view of temporal preparation presupposes that participants intentionally prepare for the moment when the IS is delivered (Los & Van den Heuvel, 2001). Central to this view is the assumption that a high preparatory state can be maintained only for a brief duration, that is, 0.1–0.3 s (Alegria, 1974; Gottsdanker, 1975). Accordingly, the individuals need to synchronize this brief preparation period with the moment of IS presentation, because optimal performance can only be achieved when the IS is occurring during this preparation period. However, the individual's strategy to anticipate the imperative moment, that is, the moment of IS presentation (Los & Van den Heuvel, 2001) greatly differs between the constant FP condition and the variable one. In the constant condition, the individual's ability to predict the imperative moment deteriorates as FP is lengthened, which in turn impairs the synchronization of the preparation period with the imperative moment at longer FPs (Näätänen, Muranen, & Merisalo, 1974). Accordingly, RT typically increases with increasing FP-length in the constant condition.

In the variable condition, however, there is not only one possible moment but several critical moments at which the IS may occur. For example, if the IS occurs with equal probability at each critical moment, the conditional probability of IS presentation during a single trial increases gradually as time goes by, that is, as the

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FP ages (Niemi & Näätänen, 1981, p. 137). It is usually believed that individuals become aware of this probability increase. As a result, their expectancy about IS occurrence growths gradually with the aging of FP. This growth of expectancy is assumed to enlarge the preparatory state, producing short RTs at a long FP_n and thus accounting for the observed FP–RT effect in the variable condition (Niemi & Näätänen, 1981; Sollers & Hackley, 1997). Thus, the classical view can explain the basic FP–RT effects.

Los and coworkers (Los & Heslenfeld, 2005; Los, Knol, & Boers, 2001; Los & Van den Heuvel, 2001), however, have recently challenged this traditional view of an intentionally driven preparation process. They put forward a completely different theoretical viewpoint, arguing that response-related preparation is driven by a process of trace conditioning. In this form of classical conditioning, the unconditioned stimulus (US) is not simultaneously presented together with the conditioned stimulus (CS) but somewhat after the CS. In this situation, the CS can produce response-related activation at the moment when the US will occur (Gallistel & Gibbon, 2000; Grossberg & Merill, 1992; Machado, 1997). Pertaining to the case of temporal preparation, Los and Van den Heuvel (2001) pointed on the conceptual similarity between the trace conditioning paradigm and the temporal preparation paradigm. According to the authors, the IS corresponds to the US, whereas the WS acts as the CS that unintentionally initiates response-related activation at critical moments. In particular, their model relies on four assumptions (cf. Los & Van den Heuvel, 2001, p. 372). First, the conditioned response has scalar property, that is, the preparatory peak is sharp-edged for early critical moments but takes more time to build up and decay when the critical moment is more remote from the WS. Second, the conditioned strength at a critical moment is reinforced when the IS occurs at this moment. Third, the conditioned strength at a critical moment remains unchanged when the IS occurs at an earlier critical moment, and fourth, decreases when the IS occurs at a later critical moment. Los (2004, p. 120) further specified this assumption arguing that when a critical moment is bypassed, it is subject to conditioned inhibition and therefore becomes associated with non-responding. This model refers to RT as a dependent measure, which is inversely related to the strength of the conditioned response at the imperative moment.

In the constant FP condition, activation builds up only at the imperative moment. In the variable FP condition, however, the IS always occurs at random times after the WS; hence reliable response strength cannot develop. In this situation, the individuals have been shown to prepare according to FP-length of the preceding trial (Los & Van den Heuvel, 2001). That is, reinforced response strength from the previous trial carries over to the next trial and elicits response-related activation at the moment which was imperative in the previous trial. Hence, especially short RTs are implied when the FP of the preceding trial is repeated. In fact, this trial-to-trial reinforcement can readily account for the finding that RT decreases with FP in a variable FP condition (see, Los & van den Heuvel, 2001).

As indicated just before, this trial-to-trial reinforcement also implies predictions about intertrial sequential effects that have been repeatedly observed in variable FP experiments. In brief, it has often been reported that, when a particular FP is preceded by a longer one in the preceding trial, RT is longer than when the preceding FP is equally long or shorter (e.g., Baumeister & Joubert, 1969; Karlin, 1959; Schupp & Schlier, 1972; Vallesi, Shallice, & Walsh, 2007; Van der Lubbe, Los, Jaskowski, & Verleger, 2004; Woodrow, 1914; Zahn & Rosenthal, 1966). These asymmetrical sequential FP effects have become the principal argument for demonstrating the superiority of the conditioning view over the classical view. Whereas the classical view cannot suitably account for sequential effects, the conditioning view provides a rather direct and plausible account (Los & Van den Heuvel, 2001, p. 371).

There are three possible FP sequences in the variable FP condition. First, a FP can be repeated in the subsequent trial. As mentioned before, RT is predicted to be short on the subsequent trial, because response strength was reinforced at the imperative moment in the preceding trial. Second, the FP can alter from long to short. In this case, a long RT should result because the imperative moment was not reinforced in the preceding trial. Finally, the FP can alter from short to long. In this case, the conditioning account predicts relatively short RTs, because later imperative moments are less frequently bypassed and thus less frequently associated with non-responding. Accordingly, response strength to an IS should increase with FP-length and should be maximal at the latest imperative moment (see Los, 2004, p. 120, for a detailed explanation). Hence, the conditioning view implies an asymmetric sequential FP effect in that a long FP_{n-1} prolongs RT in a subsequent trial with a short FP_n, whereas a short FP_{n-1} should not produce such a prolongation.

Most studies that have reported this asymmetrical sequential effect employed FPs with a mean FP usually above one second (Appendix 1). The choice of these FP-sets appears somewhat suboptimal, since substantial empirical evidence has shown that human trace conditioning in conventional settings is usually maximal for CS–US intervals between 0.25 and 0.60 s (see Anderson, 2000, p. 41; Mauk & Buonomano, 2004). This notion also agrees with the predictions of formal conditioning models (e.g., Machado, 1997, p. 242; Moore, Choi, & Brunzell, 1998, pp. 4–8; Sutton & Barto, 1998, chap. 6). Specifically, the core assumption of these models is that a CS initiates a cascade of neural activation and when the US occurs during this process, an associative link is established between the representation of the CS and the one of the US, that is, these two representations become "time-tagged" (Moore et al., 1998; Osman, Albert, Ridderinkhof, Band, & van der Molen, 2006). The neural activation triggered by the CS, however, decays within a few seconds and, consequently, the CS–US linkage is particularly effective at short intervals but less effective at long ones. Hence, according to trace conditioning models, one should also expect an asymmetrical sequential FP effects in a short variable FP-set.

However, unlike conventional settings of trace conditioning (e.g., human eyelid conditioning) this prediction is not confirmed within the context of mental chronometry, in which mean RT typically serves as measure of performance. Karlin (1959) examined sequential FP effects with a very short FP-set. In one condition, FPs were 1.6, 2.0, and 2.4 s and the typical asymmetrical sequential FP effect was observed; in another condition, the FPs were especially short, that is, 0.4, 0.5, and 0.6 s. In this condition, an anomalous sequential FP effect was obtained, which differed entirely from those obtained at longer FPs. Specifically, RT increased with increasing FP_n after the presentation of a short FP_{n-1}, instead of the typical decrease. Furthermore, the mean FP–RT function in this condition actually increased rather than decreased with FP-length. Hence, Karlin's study provides conflicting data for the conditioning view. If sequential FP effects are the signature of trace conditioning, as proposed by Los and Van den Heuvel (2001), one would expect a clear asymmetrical sequential FP effect within this short variable FP context.

There are several factors that might be responsible for the abnormal RT pattern in Karlin's (1959) study. First, one may argue that immediate arousal effects elicited by the WS are operating at this short FP-set and thus override the effects of temporal preparation (Bertelson & Tisseyre, 1969). However, this explanation seems unlikely since arousal is largely dependent on WS intensity (Ulrich & Mattes, 1996), and this intensity was low (30 dB) in Karlin's study. Second, Karlin employed a simple instead of a choice RT task. It is therefore possible that premature responses (no catch trials were used) or occasional responses to the WS (the same tone