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The effect of a cross-trial shift of auditory warning signals on the sequential foreperiod effect

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ABSTRACT

When a warning signal (WS) precedes an imperative signal (IS) by a certain amount of time (the foreperiod, FP), responses are speeded. Moreover, this effect is modulated by the FP length in the previous trial. This sequential FP effect has lately been attributed to a trace-conditioning mechanism according to which individuals learn (and re-learn) temporal relationships between the WS and the IS. Recent evidence suggests that sensory WS attributes are critical to trigger time-related response activation. Specifically, when WS modality is shifted in subsequent trials (e.g., from auditory to visual modality), the sequential FP effect becomes attenuated. This study examined whether the sequential FP effect is reduced only by between-modality shifts or whether this attenuation generalizes to cross-trial shifts of WS attributes within modalities. We compared dimensional (low vs. high tone frequency) and qualitative shifts (pure tone vs. noise) of equal-intense auditory WS events. The results of four experiments revealed that shifts of tone frequency did not, whereas shifts of qualitative tone characteristics did attenuate the sequential FP effect. These results support the view that the WS acts as a trigger cue that unintentionally activates responses at previously reinforced critical moments.

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1. Introduction

Warning signals (WS) preceding an imperative response signal (IS) are known to speed-up responses via both top-down guided (i.e., intentional) and bottom-up triggered (i.e., unintentional) processes (Hackley, 2009; Los & Schut, 2008). In a typical experiment, the IS follows the WS by a certain duration (referred to as foreperiod, FP), enabling individuals to establish a state of nonspecific preparation at the moment of IS occurrence (referred to as the imperative moment). In a constant FP paradigm, the IS occurs regularly on time after the WS and so individuals are enabled to synchronize peak readiness with the imperative moment. In a variable FP paradigm, the IS occurs irregularly after the WS and thus individuals have little reliable information to time their preparation. Consequently, reaction times (RTs) to the IS are longer in the variable FP condition than in the constant FP condition. Moreover, in the variable FP condition, responses are usually slow in short FP trials but fast in long FP trials, yielding a downward-sloping FP-RT function (Niemi & Näätänen, 1981, pp. 137–141). This variable FP effect is usually interpreted such that the elapsing time after the WS contains information about IS occurrence, since the probability of IS occurrence increases as the FP interval becomes longer (Baumeister & Joubert, 1969; Karlin, 1959; Klemmer, 1957).

From a strategic point-of-view, the WS event is considered a meaningful signal that reminds individuals to intentionally start preparation according to task rules and instructions (Gottsdanker, 1980; Näätänen & Merisalo, 1977). Notably, even when no explicit WS is given (as is the case in serial choice reaction time tasks), individuals may strategically use kinaesthetic feedback of their previous response as a warning to start preparation for the next IS (Rabbitt & Vyas, 1980). This strategic view implies that the individuals engage in a rather abstract cognitive process of attaining preparation, using the WS event symbolically by means of rule-utilization (Bourne, 1966, pp. 19–21), that is without referencing to a particular WS exemplar or to specific sensory attributes of particular exemplars. A further important assumption of this view is that individuals actively track the time flow after the WS and enhance preparation accordingly (Näätänen, 1971; Rabbitt & Vyas, 1980; Requin & Granjon, 1969). This process of monitoring the conditional probability of IS occurrence during the FP interval is considered an intentional process that requires the controlled

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allocation of mental resources and is thus effortful in nature (Näätänen & Merisalo, 1977; Stuss et al., 2005).

According to this strategic view, the downward-sloping of RT with FP length is considered to represent the time course of the individuals' average expectation about IS occurrence (Näätänen & Merisalo, 1977). Changes in the conditional probability of IS occurrence are predicted to cause a change in the FP-RT slope. For example, when a non-aging FP distribution is used that equalizes the conditional probabilities for each critical moment (i.e., a possible moment of IS presentation), the FP-RT function typically becomes flat (e.g., Baumeister & Joubert, 1969; Zahn & Rosenthal, 1966). Furthermore, Coull and Nobre (1998) describe a mechanism similar to the conditional probability monitoring process in the context of explicit cueing studies: Individuals are considered to intentionally exploit any advance information about temporal intervals to orient attention to a time point at which the IS is expected to occur (see also, Correa, Lupiáñez, Milliken, & Tudela, 2004; Lange, Rösler, & Röder, 2003).

In contrast to the strategic view, a trace-conditioning viewpoint (Los & Agter, 2005; Los & Heslenfeld, 2005; Los, Knol, & Boers, 2001; Los & Van den Heuvel, 2001) assumes that the individuals capitalize on previously established associative connections between the WS and the moment of IS occurrence. Specifically, if a connection due to previously encountered temporal relationships is established, the WS event acts as a retrieval cue that automatically triggers response-related activation at critical moments (Los & Van den Heuvel, 2001, pp. 371–373; Los et al., 2001, p. 125). As in other models, the trace is represented as an ordered sequence (i.e., a chain) of time-tagged components. Each component is assumed to act like a conditioned stimulus, capable of triggering the subsequent event. The WS event starts an activation cascade such that one component excites the next until the IS occurs during the cascade. When the IS occurs, an associative link is established between the respective component on the time line and the IS (Los et al., 2001, p. 128). Thus, when the current FP (FP_n) resembles the foreperiod of the previous trial (FP_{n-1}), it re-activates stored memories acquired in trial $n-1$ at the exact critical moment that was imperative in the previous trial (cf. Machado, 1997; Moore, Choi, & Brunzell, 1998, for models in related domains).

According to the trace-conditioning view, the downward-sloping FP-RT function is considered to arise from sequential effects due to variable FP length. This sequential FP effect refers to the fact that responses in a short FP_n trial are slower when preceded by a long FP_{n-1} than when preceded by an equally long or shorter FP_{n-1} trial (e.g., Elliot, 1970; Karlin, 1959; Steinborn, Rolke, Bratzke, & Ulrich, 2008; Vallesi, McIntosh, Shallice, & Stuss, 2009; Van der Lubbe, Los, Jaśkowski, & Verleger, 2004). Thus, the sequential FP effect is asymmetric since it is restricted to short FP_n trials whereas long-FP_n trials are not subject to a sequential modulation. This sequential FP effect is explained by a set of conditioning rules (Los & Van den Heuvel, 2001, p. 372): Conditioned strength at critical moments is reinforced when the IS occurs at this moment, remains unchanged when the IS occurs earlier, but decreases when the IS occurs at a later critical moment. Accordingly, fast responses are predicted in FP-repetition trials because response strength was reinforced in the preceding trial. Fast responses should also occur in short-to-long FP sequences because later critical moments were not bypassed in the preceding trials. However, slow responses are predicted in long-to-short FP sequences because the short critical moment was bypassed previously, resulting in a decrease of conditioned response strength at short FP_n.

As outlined before, there are two theoretical views of how WS events are recruited for temporal preparation. (a) According to a strategic view, individuals utilize stimuli that are instructed as to symbolize the WS, and intentionally start preparation henceforward. From this perspective, therefore, variations in elementary WS attributes should not affect preparation. (b) By contrast, the trace-conditioning view assumes that the WS causes retrieval of the previous trial episode, and the preparatory process runs down similarly as in the previous trial (Los & Van den Heuvel, 2001, p. 373). From this perspective, variations in stimulus attributes are likely to affect preparation, such that a change in critical WS attributes impairs the retrieval of episodic memories. This view is supported by other models in the context of classical conditioning, procedural learning, and memory research. For example, Tulving and Thompson (1973) has argued that the probability of successful retrieval of an item stored in memory is an increasing function of the similarity between the item encountered at encoding and those presented at retrieval. This recruitment-by-similarity assumption is common to many instance-theoretic explanations of episodic memory (see also Bouton & Moody, 2004, p. 669; Logan, 1990, p. 6). Importantly, the encoding-specificity model considers retrieval an all-or-none process (retrieval is either successful or not) but evidence for gradual processes have been shown as well (cf. Turatto, Benso, Galfano, & Umiltà, 2002; Töllner, Gramann, Müller, & Eimer, 2009).

The trace-conditioning view suggests transfer effects between stimuli at training and test (here between WS events between FP_{n-1} and FP_n, respectively) that should be larger for similar than for dissimilar stimuli, and changes in stimulus attributes are expected to result in less efficient retrieval processes. In fact, recent evidence suggests that preparation is more efficient when WS modality is repeated compared to when it is shifted across subsequent trials – a finding that is in accord with the trace-conditioning view. Steinborn, Rolke, Bratzke, and Ulrich (2009) demonstrated that a repetition of WS modality from FP_{n-1} to FP_n exhibited the standard variable FP effect. Shifting WS modality, however, increased the slope of the FP_n-RT function due to an attenuation of the sequential FP effect. More specifically, a shift of WS modality increased RT in short-to-short FP sequences (when a short FP_n trial is preceded by a short FP_{n-1}), but did not affect RT in long-to-short FP sequences (when a short FP_n trials is preceded by a long FP_{n-1}). Based on these findings, a retrieval failure hypothesis was postulated, which implies that despite WS (in modality-shift trials) being sufficiently attended, successful re-instantiation of the previously encountered trial episode (FP_{n-1}) has not taken place. Consequently, stimulus-triggered preparation fails and does not aid individuals when preparing for the impending IS event, resulting in a slowing of responses especially in short FP_n trials.

Although the attenuation of the sequential FP-effect in modality-shift trials (Steinborn et al., 2009) is in line with the trace-conditioning view, the pattern of results might be interpreted in alternative ways. First, one might assume that those participants failed to attend to the WS in modality-shift trials because attention prevails in the WS modality of the previous trial. According to such an attention-based explanation, a modality shift attenuates the variable FP effect because mental focus was not sufficiently directed to the relevant WS attributes (e.g., Hommel, 2009, pp. 516–518; Spence, Nicholls, & Driver, 2001). If one does not attend to the WS at the time of its occurrence, relevant information cannot be extracted and automatic preparation is likely to fail. In order to establish a retrieval failure interpretation of WS shifts in the variable FP paradigm, it is thus necessary to show that the attenuation of the sequential FP effect occurs even when it is ensured that attention is directed to the actual WS modality (Spence et al., 2001). Second, since intensity can hardly be controlled between modalities, a shift of WS modality might have induced a change in phasic arousal (Hackley, 2009). In particular, a shift from visual to auditory WS modality may artificially speed-up RT because auditory signals are considered intrusive and more arousing than visual ones. A shift from auditory to visual WS modality may also produce artificial effects on RT but in the opposite direction (cf.

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