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

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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.

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.

Grice, 1968). To strengthen the trace-conditioning account, it is therefore necessary to demonstrate a modulation of the sequential FP-effect in WS-shift trials when WS intensity is kept constant.

The present study aimed to rule out both confounds, attention-to-modality effects (i.e., the WS is not sufficiently attended in WS-shift trials) and intensity-shift effects (i.e., the WS is especially attended when intensity increases across trials but less attended when intensity decreases across trials) by examining the effect of a repetition versus a shift of WS attributes within modalities on the sequential FP effect. The design was similar to the one of Steinborn et al.'s (2009) study. Specifically, two WS events were randomly varied within blocks of trials in a variable FP paradigm. In contrast to the previous study, the shift from one WS event to the next occurred exclusively within the auditory modality. According to our knowledge, no study so far has examined within-modality WS-shift effects in temporal preparation. Thus it seemed natural to employ well-distinguishable pure tones (i.e., 1000 and 1400 Hz). Taking recent developments in related domains into account, we also considered shifts between qualitative tone characteristics (e.g., Schröter, Ulrich, & Miller, 2007), different task conditions (e.g., Correa et al., 2004), and levels of temporal uncertainty (e.g., Karlin, 1959; Steinborn et al., 2009). In all experiments, it was ensured that the WS stimuli were easy to distinguish and of similar sound intensity. If the modality-shift effect reported by Steinborn et al. merely reflects a failure of attending the appropriate sensory modality in modality-shift trials, a within-modality shift of WS features should not modulate the sequential FP effect.

2. Experiment 1

In Experiment 1 (two-choice RT task), a variable FP paradigm (FPs: 1200 vs. 3600 ms) was employed in which two well-distinguishable auditory WS (1000 vs. 1400 Hz) were randomly varied within blocks of trials. If a shift between tone frequencies affects trace-conditioning, as has been demonstrated for shifts between modalities (Steinborn et al., 2009), the sequential FP effect should be attenuated. This would be indicated by a significant WS-SEQ $\times$ $FP_{n-1} \times FP_n$ interaction effect.

2.1. Method

2.1.1. Participants

Thirty-five (8 male, 27 female) volunteers (mean age = 24.7 years, SD = 5.7) took part in the experimental session. All participants but six were right-handed and all of them had normal or corrected-to-normal vision.

2.1.2. Stimuli and apparatus

The experiment took place in a dim and noise-shielded room; it was run on a standard IBM computer with color display (19", 150 Hz refresh rate) and programmed in MATLAB™ using the Psychophysics Toolbox extensions (Brainard, 1997). Participants were seated at a distance of about 60 cm in front of the computer screen. A dot sign ($0.5° \times 0.5°$ angle of vision) served as fixation point and therefore was constantly presented throughout the experimental session in the middle of the screen. The auditory WS (either 1000 or 1400 Hz frequency; 70 dB SPL) was binaurally presented via headphones for 200 ms. All participants reported that they could easily judge the difference between the two pure tones. The letters "L" and "R" ($1.14° \times 0.86°$ angle of vision) served as the IS and were presented visually, displayed in blue (7.1 cd/m^2) at the centre of the screen.

2.1.3. Design and procedure

Participants performed a two-choice response task and were required to respond with either the left shift-key (left index finger in case of "L") or the right shift-key (right index finger in case of "R"). We used a three-factorial within-subject design, with the factors WS-SEQ (repetition vs. shift), FP_{n-1}, (short vs. long), and FP_n (short vs. long). A trial started with the presentation of the WS, followed by a blank FP interval after which the IS was presented. The IS was terminated either by the participants' response or by response interval expiration (i.e., after 2000 ms). A constant intertrial interval of 1500 ms separated subsequent trials. Participants were instructed to respond quickly and accurately to the IS. Feedback was given only in case of an erroneous response or in case of response interval expiration. In case of an erroneous response, the word "falsch" (wrong) was presented for 300 ms, whereas in case of response interval expiration, the words "zu langsam" (too slow) were presented for 300 ms. The participants performed 48 practice trials and 1040 experimental trials during the session, with a short break given after a block of 150 trials. The overall session lasted about 90 min.

2.2. Results and discussion

Responses faster than 100 ms and slower than 1000 ms were considered outliers and discarded from the analysis (0.5%). Trials following feedback trials (erroneous responses, too slow response) were also excluded. Erroneous responses were scored as index of error percentage. A three-factorial within-subject analysis of variance (ANOVA) was performed, with WS-SEQ (repetition vs. shift), FP_{n-1} (short vs. long), and FP_n (short vs. long) as factors and RT as the main dependent variable. All main and interaction effects are listed in Appendix 1 and only the theoretically relevant effects are subsequently reported in more detail. Fig. 1 displays RT and error percentage for WS repetition (Panel A and C) and WS-shift trials (Panel B and D).

Although the present experiment produced a clear sequential FP effect as indicated by the highly significant $FP_{n-1} \times FP_n$ interaction, this effect was not significantly modulated by a cross-trial shift of WS tone frequency (from low-to-high, or high-to-low) as shown by the non-significant WS-SEQ $\times$ $FP_{n-1} \times FP_n$ interaction ($F < 1$). This suggests that changes in WS tone frequency enabled a full cross-trial transfer of response activation. However, there was a significant WS-SEQ $\times$ FP_{n-1} interaction on RT [$F(1,34) = 18.6$; partial $\eta^2 = 0.35$; $p < 0.001$]: the WS-shift had a detrimental effect on RT performance after a short FP_{n-1} trial but not after a long FP_{n-1} trial. The results of Experiment 1 therefore show that even shifts of tone frequencies had a moderate effect on performance. Importantly, since there was no three-way interaction on RT, the results of Experiment 1 do not allow the conclusion that a shift of WS tone frequency affects the asymmetry of the sequential FP effect.

3. Experiment 2

Experiment 2 (FPs: 1200 and 3600 ms; choice RT) was conducted to examine whether the sequential FP effect is modulated when the auditory WS stimuli differ in a qualitative way, rather along a single physical dimension. Accordingly, we used a pure tone (1000 Hz frequency) and broadband noise (white noise) as WS in Experiment 2. If a cross-trial shift of WS identity attenuates the sequential FP effect, this should be indicated by a significant WS-SEQ $\times$ $FP_{n-1} \times FP_n$ interaction effect on RT.

3.1. Method

3.1.1. Participants

Thirty-five (8 male, 27 female) volunteers (mean age = 22.1 years, SD = 2.1) took part in the experimental session. All

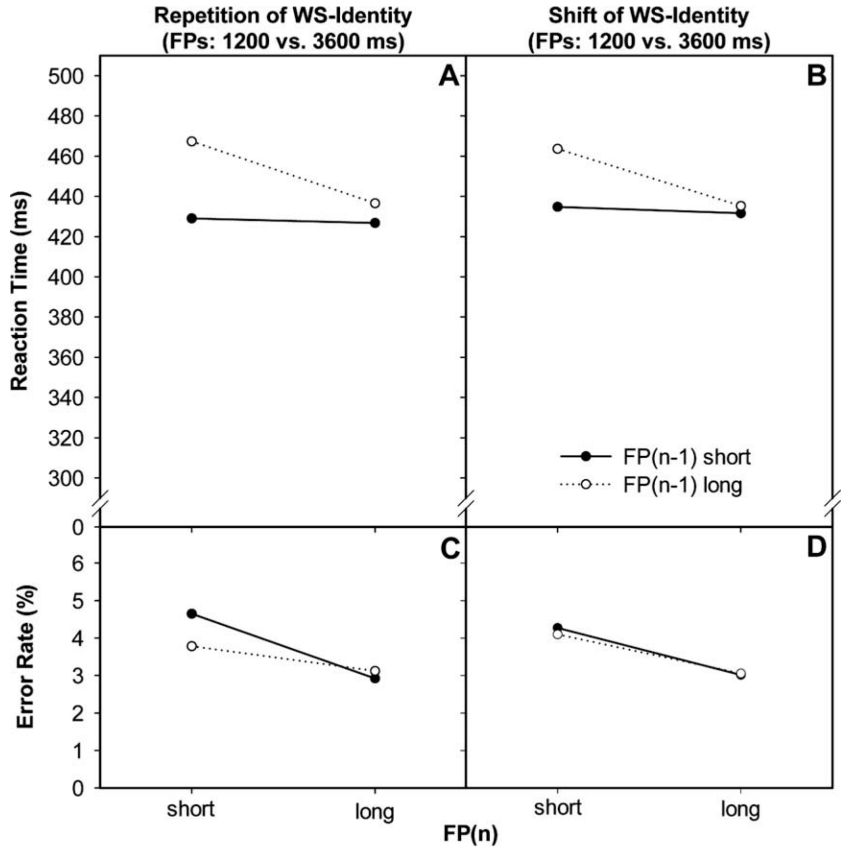

Fig. 1. Effect of a repetition versus a shift of WS identity (low vs. high tone frequency) on sequential FP effects in Experiment 1. Reaction time and error percentage displayed as a function of the preceding foreperiod (FP_{n-1}) and the current foreperiod (FP_n), separately for WS repetition trials (panel A and C) and WS-shift trials (panel B and C).

participants but three were right-handed and all of them had normal or corrected-to-normal vision.

3.1.2. Stimuli and apparatus

The experimental setting was exactly the same as in Experiment 1 and only the WS pairing was different. The auditory WS (pure tone of 1000 Hz vs. white noise; 70 dB SPL) was binaurally presented via headphones for 200 ms.

3.1.3. Task, design and procedure

The task, the design and the procedure were the same as in Experiment 1, except that a different WS pairing (i.e., pure tone vs. white noise) was used. We used a three-factorial within-subject design, with the factors WS-SEQ (repetition vs. shift), FP_{n-1} (short vs. long) and FP_n (short vs. long), and RT as the main dependent measure.

3.2. Results and discussion

Responses faster than 100 ms or slower than 1000 ms were considered outliers and their corresponding trials (0.5%) were discarded from the analysis. Trials following feedback trials (erroneous responses, too slow response) were also excluded. Erroneous responses were used to compute the percentage of errors. A three-factorial within-subject analysis of variance (ANOVA) was performed, with WS-SEQ (repetition vs. shift of WS identity), FP_{n-1} (short vs. long) and FP_n (short vs. long) as factors and RT as the main dependent variable. Fig. 2 summarizes the results and depicts RT and error percentage as a function of FP_{n-1} and FP_n, separately for WS repetition (Panel A and C) and WS-shift trials (Panel B and D). All main and interaction effects are listed in Appendix 1 with the relevant effects discussed subsequently.

A significant WS-SEQ $\times$ FP_{n-1} $\times$ FP_n interaction effect was observed [1,34) = 8.9; partial $\eta^2 = 0.21$; $p < 0.01$] indicating that the size of the asymmetric sequential FP effect was larger when WS identity was repeated compared to when it was shifted (see Fig. 2). When WS identity repeated, the sequential effect at short FP_n (i.e., RT after a long-FP_{n-1} minus RT after a short FP_{n-1}) was 33 ms. This effect decreased to 24 ms when WS modality shifted. Thus, a shift of WS modality attenuated the sequential modulation at short FP_n by 18%. Consistent with previous findings (Steinborn et al., 2009), responses were always fast in long-FP_n trials, irrespective of the length of FP_{n-1} and irrespective of whether WS modality was repeated or shifted. This indicates that the WS triggers the conditioned response mainly in short FP_n trials but has virtually no influence in long-FP_n trials. Also note that error rate varied only in a small range (Fig. 2) and that there were no statistical effects on error rate (Table 1). This clearly indicates that the results are not confounded by a speed–accuracy tradeoff (Table 2).

4. Experiments 3

In Experiment 2, we were able to demonstrate that a modulation of the sequential FP effect can even occur when WS is shifted within modalities, using tones and noise as WS stimuli. Since effect size was small, we asked whether a more pronounced modulation could be revealed with a greater degree of time and occurrence uncertainty. It has been demonstrated that an increase in time uncertainty results in a stronger modulation of the sequential FP effect due to a shift of WS modality (Steinborn et al., 2009). Experiment 3 therefore was conducted to replicate the results obtained in Experiment 2,

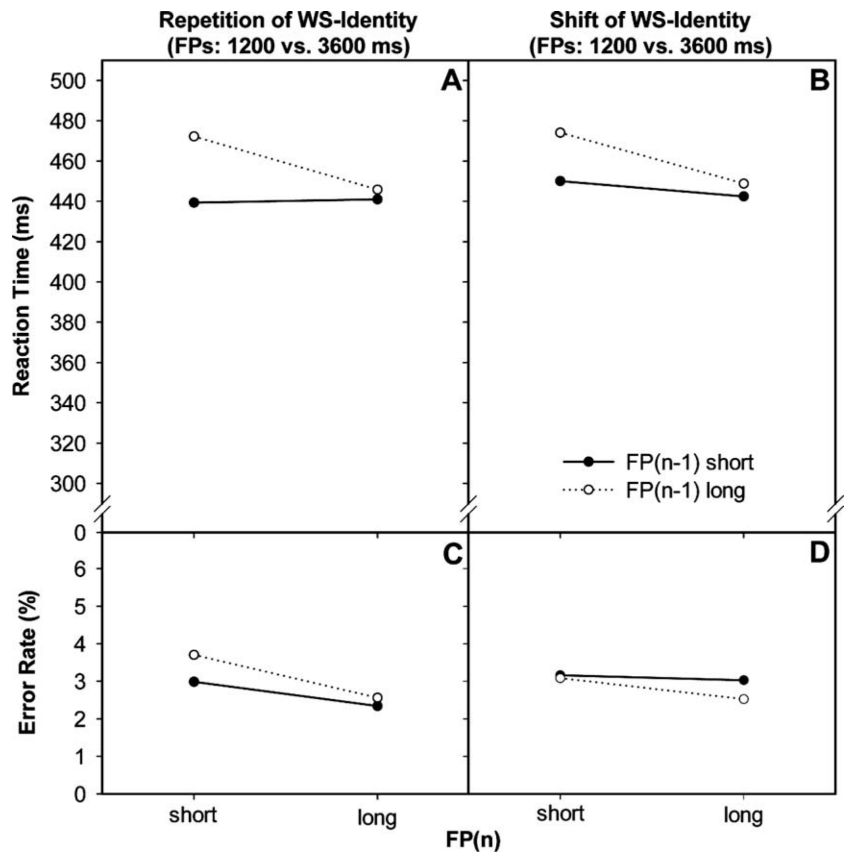

Fig. 2. Effect of a repetition versus a shift of WS identity (pure tone vs. white noise) on sequential FP effects in Experiment 2. Reaction time and error percentage displayed as a function of the preceding foreperiod (FP_{n-1}) and the current foreperiod (FP_n), separately for WS repetition trials (panel A and C) and WS-shift trials (panel B and C).

similarly using a pure tone and white noise as WS stimuli. In addition, we used three instead of only two FPs, and a broader FP-range (FPs: 1000, 2500, and 4000 ms). Since sequential effects are larger when a simple RT task is used, as has been empirically verified in several studies (e.g., Correa et al., 2004; Steinborn et al., 2008), we employed a simple RT task instead of a choice RT task.

4.1. Method

4.1.1. Participants

Thirty-one (11 male, 20 female) volunteers (mean age = 23.0 - years, SD = 3.0) took part on the experimental session. All participants but two were right-handed and all of them had normal or corrected-to-normal vision.

4.1.2. Stimuli and apparatus

The experimental setting in Experiment 3 was identical to the previous experiments except that we used three FPs (1000, 2500, and 4000 ms), and two auditory WS events (pure tone vs. broadband noise).

4.1.3. Task, design and procedure

The task, the design and the procedure were identical to those of Experiments 1 and 2 with the exception that participants always had to respond with the right index finger irrespective of whether the letter “L” or “R” was presented as the IS. The within-subject design was three-factorial with the factors WS-SEQ (repetition vs. shift), FP_{n-1} (short vs. medium vs. long) and FP_n (short vs. medium vs. long), and with RT as the main dependent measure.

4.2. Results and discussion

Trials with RTs shorter than 100 ms or longer than 1000 ms were discarded from RT analysis (0.5%). Premature responses and trials with RTs shorter than 100 ms were defined as anticipatory responses. Fig. 3 summarizes the results and depicts RT as a function of FP_{n-1} and FP_n, separately for each level of WS-SEQ: repetition of WS identity (Panel A) and shift of WS identity (Panel B). All main and interaction effects are listed in Appendix 1 and only the theoretically relevant effects are subsequently referred to.

The WS-SEQ × FP_{n-1} × FP_n interaction effect [(4,120) = 6.2; partial $\eta^2 = 0.17$; $p < 0.001$] replicated the results of Experiment 2, indicating a modulating influence of the factor WS-SEQ on the sequential FP effect. Again, shifting WS identity from trial $n-1$ to trial n attenuated the asymmetry of the sequential FP effect. When WS identity repeated, the sequential effect at short FP_n (i.e., RT after a long-FP_{n-1} minus RT after a short FP_{n-1}) was 68 ms. In agreement with our expectations, the sequential FP effect in Experiment 3 was larger than that observed in Experiment 2 (compare Figs. 2 and 3). This effect decreased to 47 ms when WS modality shifted. Thus, a shift of WS modality attenuated the sequential modulation at short FP_n by 31%. Accordingly, the relative attenuation of the sequential FP effect at short FP_n was larger than in Experiment 2 (18%). In addition, the factor WS-SEQ had a strong influence on RT in short FP_n trials but affected RT only minimally in medium FP_n trials and not at all in long-FP_n trials (Fig. 3). In each of the two WS-SEQ conditions, there were only a small percentage of anticipatory responses.

5. Experiment 4

In both Experiments 2 and 3 (WS = tone vs. noise), we were able to demonstrate a modulation of the sequential FP effect due to a

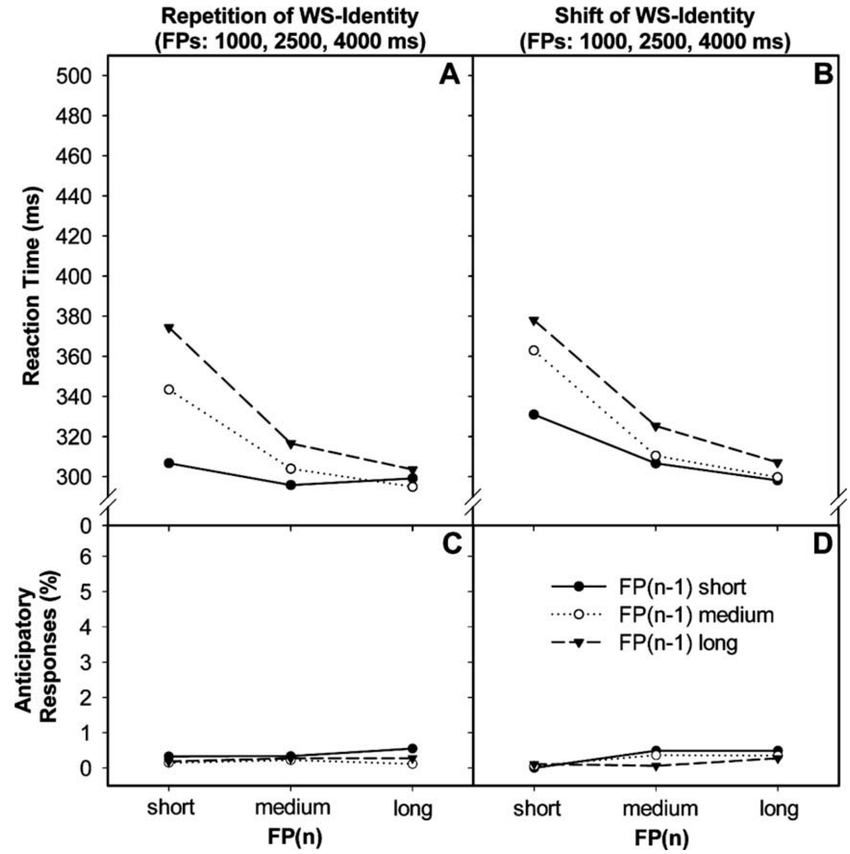

Fig. 3. Effect of a repetition versus a shift of WS identity (pure tone vs. white noise) on sequential FP effects in Experiment 3. Reaction time and percentage of anticipatory responses displayed as a function of the preceding foreperiod (FP_{n-1}) and the current foreperiod (FP_n), separately for WS repetition trials (panel A and C) and WS-shift trials (panel B and C).

shift between WS attributes within modalities. In addition, the attenuation of the sequential FP effect was larger with greater time uncertainty. In contrast, Experiment 1 (WS = low vs. high tone) did not yield a modulation of the sequential FP effect. In Experiment 4 (WS = low vs. high tone), therefore, we aimed to check whether a greater degree of time uncertainty would actually yield a modulation of the sequential FP effect due to a shift between WS tone frequencies. As in Experiment 3, we used three FPs, a broad FP-range (FPs: 1000, 2500, 4000 ms), and a simple RT task. By means of this more sensitive manipulation, we asked whether it is possible to demonstrate an attenuation of the sequential FP effect even with tone–tone shifts of WS identity.

5.1. Method

5.1.1. Participants

Thirty-two (8 male, 24 female) volunteers (mean age = 24.4 -years, SD = 4.3) took part in the experiment which took place at different experimental sessions. All participants but one were right-handed and all of them had normal or corrected-to-normal vision.

5.1.2. Stimuli and apparatus

The experimental setting in Experiment 4 was identical to the previous experiments. Here, three FPs (1000, 2500, 4000 ms) and a simple RT task were used.

5.1.3. Task, design, procedure

Design and procedure were identical to the previous experiments.

5.2. Results and discussion

Trials with RTs shorter than 100 ms or longer than 1000 ms were discarded from the analysis (0.5%). Premature responses and trials with RTs shorter than 100 ms were defined as anticipatory responses. Fig. 4 depicts RT as a function of FP_{n-1} and FP_n, separately for each level of WS-SEQ: repetition of WS identity (Panel A) and shift of WS identity (Panel B). All main and interaction effects are listed in Appendix 1.

Similar as in Experiment 1, there was again a significant WS-SEQ $\times$ FP_{n-1} interaction on RT [$F(2,62) = 3.4$; partial $\eta^2 = 0.09$; $p < 0.05$]: the WS-shift had a detrimental effect on RT after a short FP_{n-1} trial but not after a long FP_{n-1} trial. Thus, Experiment 4 shows again some moderate effect of a shift of WS tone frequency on RT performance. Most importantly, Experiment 4 did not reveal the critical WS-SEQ $\times$ FP_{n-1} $\times$ FP_n interaction effect ($F < 1$). Thus, shifts between tone frequencies did not attenuate the asymmetric sequential FP effect, replicating the result of Experiment 1 (see Table 1, Fig. 1). Since all the participants were capable of easily judging the difference between the tones, the results may not be interpreted such that the tone frequencies used (1000 vs. 1400 Hz) were not sufficiently different to reveal a modulation of the sequential FP effect.

6. General discussion

According to a trace-conditioning view of temporal preparation, WS events have the capability to retrieve previously encountered trial episodes, and by this means automatically trigger response activation to an impending IS (Los & Van den Heuvel, 2001, p.

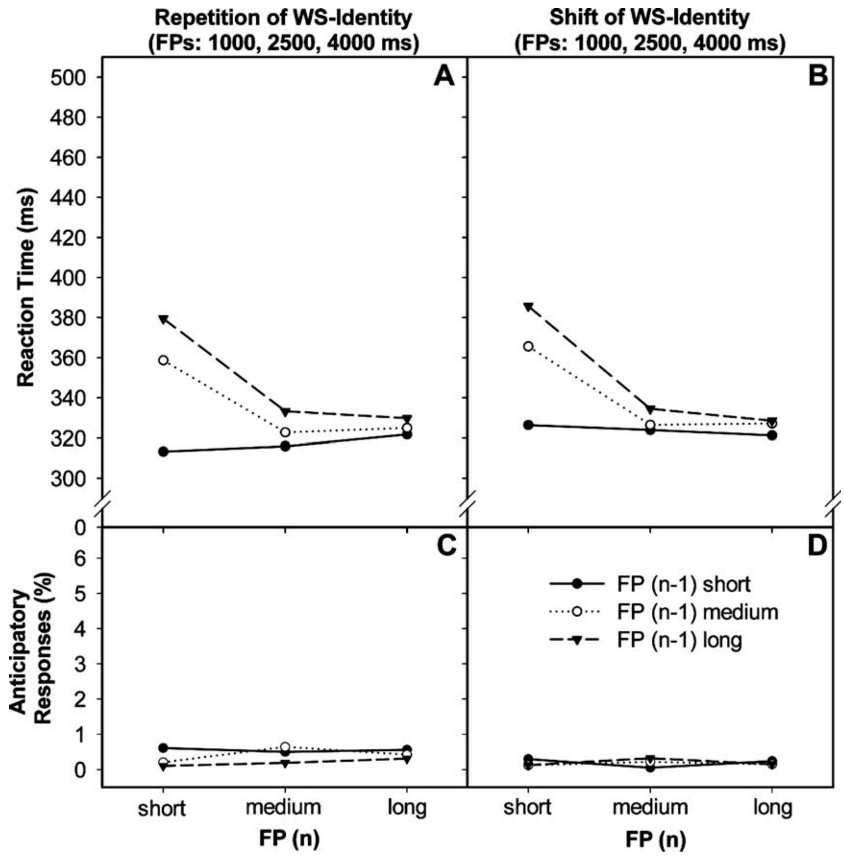

Fig. 4. Effect of a repetition versus a shift of WS identity (low vs. high tone frequency) on sequential FP effects in Experiment 4. Reaction time and percentage of anticipatory responses displayed as a function of the preceding foreperiod (FP_{n-1}) and the current foreperiod (FP_n), separately for WS repetition trials (panel A and C) and WS-shift trials (panel B and C).

371). This is indicated by the sequential FP effect, considered to reflect trial-to-trial temporal learning in the variable FP paradigm. Consistent with this view, it has been shown that when WS modality shifts across trials, the sequential FP effect is attenuated (Steinborn et al., 2009). Here we identified two issues associated with between-modality shifts, that might complicate an interpretation of such WS modality-shift effects in terms of episodic retrieval: differences in WS stimulus intensity (Hackley, 2009), and attention-to-modality effects (Spence et al., 2001). Since WS intensity can hardly be equalized across modalities, we argued in the introduction that any modulation could be attributed to arousal differences. Additionally, since between-modality shifts may also have caused a failure of attending to the actual WS modality in a particular trial, any modulation cannot unequivocally be interpreted in terms of failed memory retrieval.

To explain the attenuation of the sequential FP effect in terms of episodic retrieval, it seemed necessary to demonstrate similar effects of WS shifts in situations where both the intensity and the modality of the WS are controlled for. As mentioned above, this is only possible when WS attributes change within a particular modality. Therefore, we conducted four experiments in which two auditory WS events were randomly varied. In addition, we considered different WS combinations, task forms and levels of temporal uncertainty. The results demonstrate that even a shift of equally intense auditory WS events can attenuate the sequential FP effect (Experiment 2 and 3: tone vs. noise), with effect sizes similar to the findings observed between modalities (Steinborn et al., 2009). We argue that the present results provide a strong argument against an encoding-failure explanation of the WS-shift effect, which implies that WS attributes are not sufficiently attended in WS-shift trials. Instead, the results support a retrieval-failure explanation, which implies that episodic memories are not, or at least less efficiently, retrieved in WS-shift trials.

6.1. Role of the warning signal in temporal preparation

The present results indicate that the WS in variable-FP experiments triggers time-point specific response activation automatically. According to the trace-conditioning model of temporal preparation (e.g., Los & Van den Heuvel, 2001, p. 373; Los et al., 2001, p. 128), the WS event initiates a cascade of sensory events. In this sense, each event is sequentially bound on a time-line and after the WS event, activation wanders through this sequence as a train of sensation (Moore et al., 1998; Smallwood, Nind, & O'Connor, 2009). When an overt response is made to the IS at a particular critical moment on this time line, the response then becomes connected with those sensory elements in the chain that are activated at this trial. Since previously encountered trial episodes are stored in episodic memory, an identical WS event is capable of directly activating stored memories and by this means triggers preparatory activity in subsequent trials (see also, Machado, 1997; Moore et al., 1998). If, however, a WS event is presented which sufficiently differs from that one presented previously, episodic memories will not (or less likely) be retrieved and automatic (stimulus-triggered) preparation will fail in this particular trial (Tulving & Thompson, 1973).

The present study extends previous results on between-modality shifts (Steinborn et al., 2009) by demonstrating that the sequential FP effect can also be modulated by shifts within WS modalities. This was the case for shifts between tones and noise (Experiments

2 and 3). Consistent with the assumptions of the trace-conditioning model (Los & Van den Heuvel, 2001, p. 373; Los et al., 2001, p. 128), response activation in a current trial was stronger (i.e., responses were faster) for WS repetitions (e.g., noise-to-noise; tone-to-tone) than for WS shifts (e.g., noise-to-tone; tone-to-noise). Interestingly, this happened even though both WS modality and intensity were kept constant, suggesting that successful re-instantiation of the FP_{n-1} trial episode depends crucially on the specific auditory characteristics of the WS. Therefore, we suggest that our participants are less likely to benefit from reinforcement in trial FP_{n-1} after a shift of the WS event, most probably due to a failure of getting access to previously experienced trial episodes and not to a failure of attending to the WS itself at the moment of its occurrence. Although such a retrieval-failure explanation might imply an all-or-none process (retrieval is either successful or not), it should be mentioned that this does not argue against the possibility that inefficient retrieval can also occur in a rather gradual fashion, especially in situation where retrieval cues contain multiple attributes (e.g., Harris, 2006; Rescorla & Wagner, 1972; Wagner, 2008).

Interestingly, the WS in Experiments 2 and 3 exerted its influence exclusively at short critical moments but not at later ones. When a short FP_n is preceded by a long FP_{n-1}, a shift from tone to noise (or noise to tone) has virtually no effect on RT. As previously stated (Steinborn et al., 2009), we suggest that the WS triggers response activation only at short critical moments but not at later ones. This interpretation is in line with the trace-conditioning view (Los & Van den Heuvel, 2001, p. 373; Los et al., 2001), which assumes that responses at late imperative moments are consistently fast because they are less frequently extinguished and may not benefit additionally from WS-triggered activation. Furthermore, it is also possible that the sensory attributes of a WS decay rapidly and thus are available only at short critical moments, whereas the conceptual attributes (i.e., the symbolic meaning) have a longer persistency (Glenberg & Swanson, 1986). Therefore, the finding that WS features have no influence in long-FP_n trials is also consistent with a strategic view (Näätänen, 1971; Näätänen & Merisalo, 1977; Rabbitt & Vyas, 1980), according to which fast responses in long-FP_n trials arise from an effortful and intentionally guided process of conditional probability monitoring that dominates response preparation at late imperative moments. However, since the trace-conditioning model also predicts fast responding regardless of whether the last WS is repeated or not, it provides the most parsimonious account for the present findings.

Contrary to a strategic view, however, the trace-conditioning model provides a theoretical basis to address cross-trial WS shifts in variable-FP experiments, since this model considers the WS event a trigger signal that automatically initiates preparatory activity (Los & Van den Heuvel, 2001, p. 373; Los et al., 2001, p. 128). Thus, the present study corroborates the idea that WS events speed-up responses not only via mechanisms of automatic alerting (Hackley, 2009) or strategic preparation (Näätänen, 1971; Näätänen & Merisalo, 1977) but because of their capability to retrieve previously established association between WS, time, and IS. However, saying that a strategic view cannot explain the present findings does not generally argue against strategic models of temporal preparation. It is clear that performance in RT experiments depends critically on the participants' general intention to respond quickly to the IS (cf. Los & Van den Heuvel, 2001, p. 373). Fluctuations in the participants' energetical state or problems in the ability to maintain alertness (Vallesi, McIntosh, & Stuss, 2009; Vallesi & Shallice, 2007; Zahn, Kruesi, & Rapoport, 1991) may be a source of performance effects that is entirely different from temporal associative learning. Thus, the need for a general intention to comply with the task constraints and to energize behavior for speeded responding makes it unlikely that trace-conditioning is the only mechanism that affects performance in variable foreperiod paradigms.

According to Hebb (1955), every sensory stimulation that comprises a warning signal has two different functions: a cue function and an arousal function. The cue function represents the information associated with the stimulation (here, the previous trial episode) and the arousal function energizes behavior. The trace-conditioning view (Los & Van den Heuvel, 2001) focuses on the cue function but not on the arousal function. However, a recently proposed dual-process view (Vallesi & Shallice, 2007; Vallesi, Shallice, & Walsh, 2007; Vallesi, McIntosh, & Stuss, 2009) takes arousal into account: Responses in short FP_n trials are assumed to be facilitated after a short FP_{n-1} (due to a response-generated increase in arousal) but especially slow after a long FP_{n-1} (due to a decrease in arousal). In long-FP_n trials, however, responses are fast because the arousal decrement can be compensated by a strategic conditional probability monitoring process (see also Näätänen, 1971; Rabbitt & Vyas, 1980). Thus, the dual-process model can also explain the present finding that a WS shift had no effects on RT in long-FP_n trials. Without explicitly considering an associative learning mechanism of WS–IS relationships, however, the dual-process view cannot account for the effect of a shift of WS attributes on the sequential FP effect.

6.2. Sources of cross-trial transfer in WS-shift trials

Although a shift of WS identity had a modulating influence on temporal preparation, there was a substantial residual sequential FP effect in WS-shift trials. The effect was similar in size as the one recently observed in between-modality shift trials (Steinborn et al., 2009), and may be explained in terms of stimulus generalization. It has long been recognized that performance on a retrieval task tends to be superior when the test context is similar to that experienced during training, or the previous trial, respectively (Taatgen, Huss, Dickison, & Anderson, 2008; Tulving & Thompson, 1973). Often, performance deteriorates when stimulus modality changes from the training to the test period, or from the previous to the current trial, respectively (e.g., Gondan, Lange, Rösler, & Röder, 2004; Quinlan & Hill, 1999; Roediger & Blaxton, 1987; van Dantzig, Pecher, Zeelenberg, & Barsalou, 2008). Subsequently, we will discuss three possible sources of stimulus generalization which may explain the residual sequential FP effect: (1) feature overlap (the warning signals share common properties: loudness), (2) concept overlap (the same if-then rules, or task instructions, are contingent to the warning), and (3) strategic preparation.

First, our results indicate that cross-trial WS-shift effects on RT depend crucially on the extent to which auditory stimuli differ qualitatively from each other. Whereas shifts of tone frequency enabled cross-trial transfer and thus did not attenuate the asymmetric sequential FP effect (Experiments 1 and 4), shifts between tones and noise (Experiments 2 and 3) seem to differ physically enough as to reveal a modulation of the effect. It should be noted, that Experiments 1 and 4 showed a detrimental effect of a shift of WS tone frequency on RT performance, since RT was somewhat prolonged after a short FP_{n-1} but not after a long FP_{n-1}. Since these two experiments, however, did not reveal the critical three-way interaction, it is nevertheless likely that the pure tones, even though differing in frequency, were regarded similar by the cognitive system (i.e., a class of elemental-level events, Harris, 2006). In contrast, the percept of a pure tone may be entirely different from the percept established by broadband noise (cf. Schröter, Frei, Ulrich, & Miller, 2009; Schröter et al., 2007, for a discussion in a related domain). If pure tones are classified into a common perceptual class, it follows that WS-triggered response activation is not restricted to the precise stimulus encountered previously but may generalize to other similar stimuli from the same perceptual class. Thus, a shift of tone frequency may have yielded the activation of a rather identical cascade of sensory events, whereas a shift from tone to noise (or noise to tone, respectively) did yield the activation of a distinct cascade. It makes sense to assume that the more features the two warning signals differ by, the less likely the identical cascade will be activated and the more the sequential FP effect will be attenuated. From the perspective of a *feature-overlap hypothesis*, therefore, the residual sequential FP effect may indicate the degree to which preparation is not exclusively triggered by specific WS attributes but by unspecific stimulation that is common to all WS events (cf. Hackley et al., 2009).

Second, the residual sequential FP effect could alternatively result due to concept formation that enables a rather symbolic use of WS events for preparation. In conditioning models, such a mechanism is described as involving the learning of a common (or similar) conditioned response to two or more distinguishable conditioned stimuli (cf. Bourne, 1966; Martin, 1968). Here, the commonality is not on the perceptual level (i.e., the degree of feature overlap) but on the conceptual level at which stimuli are mentally represented (i.e., the degree of function overlap). For example, if a child learns that objects as dissimilar as a train, a bicycle, or a car, are all vehicles, it is helped to deal with them in terms of their common properties as a means of transportation (Bourne, 1966). Analogously, if our participants have learned that the auditory WS events are all symbols that signature the start of a trial (even though dissimilar with respect to their perceptual identity), this could have enabled them to engage in rather abstract cognitive processes to accomplish preparation. Concept formation as classification occurs when conditioned stimuli share the same symbolic meaning, irrespective of their perceptual identity. It has been shown that abstraction becomes more dominant when more stimuli are mapped onto the same unconditioned response, known as the encoding-variability principle (Martin, 1968). From a *concept-overlap hypothesis*, the residual sequential FP effect should therefore increase when more different WS events are used in a variable FP paradigm.

Third, the residual sequential FP effect might simply reflect the contribution of strategic preparation. According to a strategic view, individuals employ the WS symbolically and then intentionally start preparation henceforward (Näätänen & Merisalo, 1977). The critical difference to the aforementioned explanations is that the WS does not directly activate preparatory activity but first activates the goal (its mental representation), which then activates preparatory activity. In the conditioning literature, goals are considered to act like a (compound) conditioned stimulus (cf. de Wit & Dickinson, 2009; Hommel, 2009): with repeated exposure, therefore, even goal representations can acquire the capability to automatically trigger response activation (cf. Bargh & Gollwitzer, 1994; Verbruggen & Logan, 2009; Verguts & Notebaert, 2008, for a related discussion). Thus, the degree to which WS attributes become associated with the representation of goals (or parts of them, e.g., explicit rules, motivational forces, respectively) may determine the size of the residual sequential FP effect. Strategic preparation may also include proactive attentional strategies to optimize the processing of WS information. For example, it has been proposed that participants are capable of statistically learning the probability of which a stimulus occurs in a particular modality, and adjusting their expectations according to this probability (e.g., Turatto et al., 2002; Töllner et al., 2009). According to such an expectancy-weighting account, individuals may also learn to attend to features of stimuli within one modality according to the probability of their occurrence. Since the two WS stimuli occurred with the same frequency (50:50) in our experiments, there is reason to assume that our participants expected both auditory WS events to the same degree and therefore, in a given trial, oriented attention to both possible WS events. Notably, the presented experiments were not conducted to discriminate between possible sources of the residual sequential FP effect. They may nevertheless provide the theoretical basis to derive predictions about WS-identity shifts in variable-FP experiments in the future.

6.3. Conclusion

Taken together, the results of the present study provide strong evidence for a retrieval-failure account of WS-shift effects in temporal preparation. We showed that a within-modality shift of equally intense WS events can modulate sequential effects in the variable FP paradigm. By this means, the present study extends previous results on between-modality shifts (cf., Steinborn et al., 2009), ruling out the possibility that the attenuation of the sequential FP effect is due to a failure of attending to the correct WS modality (since the WS events were always in the same modality), or a failure of sufficiently attending to the WS in general (since auditory WS events are naturally intrusive). In line with the trace-conditioning account (Los & Van den Heuvel, 2001; Los et al., 2001), the present study provides further evidence that

Table 1
ANOVA results for Experiments 1 and 2.

	Source	*dfs*	Reaction time *F*	*p*	η^2	Error percentage *F*	*p*	η^2
			Experiment 1 (WS = low vs. high pure tone)					
1	WS-SEQ	1.34	1.4	0.247	0.04	0.0	0.949	0.00
2	FP_{n-1}	1.34	132.0	0.001	0.80	3.1	0.085	0.08
3	FP_n	1.34	38.6	0.001	0.53	11.2	0.002	0.25
4	WS-SEQ × FP_{n-1}	1.34	18.6	0.001	0.35	0.3	0.605	0.01
5	WS-SEQ × FP_n	1.34	0.0	0.861	0.00	0.0	0.974	0.00
6	FP_{n-1} × FP_n	1.34	102.9	0.001	0.75	1.4	0.252	0.04
7	WS-SEQ × FP_{n-1} × FP_n	1.34	0.6	0.442	0.02	0.53	0.472	0.01
			Experiment 2 (WS = pure tone vs. white noise)					
1	WS-SEQ	1.34	10.7	0.002	0.24	0.1	0.749	0.00
2	FP_{n-1}	1.34	137.6	0.001	0.80	0.2	0.676	0.01
3	FP_n	1.34	27.0	0.001	0.44	6.2	0.018	0.16
4	WS-SEQ × FP_{n-1}	1.34	3.6	0.068	0.10	3.8	0.060	0.10
5	WS-SEQ × FP_n	1.34	2.8	0.099	0.08	1.7	0.206	0.05
6	FP_{n-1} × FP_n	1.34	58.6	0.001	0.63	1.6	0.212	0.05
7	WS-SEQ × FP_{n-1} × FP_n	1.34	8.9	0.005	0.21	0.0	0.932	0.00

Note. *Effect size:* partial η^2; FPs: 1200 and 3600 ms, *factors:* WS-sequence (WS-SEQ: repetition of WS identity vs. shift of WS identity), previous foreperiod (FP_{n-1}: short vs. long), current foreperiod (FP_n: short vs. long).

Table 2
ANOVA results for Experiments 3 and 4.

	Source	dfs	Reaction time			Anticipatory responses		
			F	p	η^2	F	p	η^2
			Experiment 3 (WS = pure tone vs. white noise)					
1	WS-SEQ	1.30	29.2	0.001	0.49	0.2	0.638	0.00
2	FP_{n-1}	2.60	110.8	0.001	0.79	4.4	0.017	0.13
3	FP_n	2.60	106.8	0.001	0.78	2.3	0.123	0.07
4	WS-SEQ × FP_{n-1}	2.60	3.1	0.058	0.09	2.2	0.183	0.05
5	WS-SEQ × FP_n	2.60	10.5	0.001	0.26	1.8	0.333	0.03
6	FP_{n-1} × FP_n	4.120	74.4	0.001	0.71	1.0	0.309	0.04
7	WS-SEQ × FP_{n-1} × FP_n	4.120	6.2	0.001	0.17	0.9	0.443	0.03
			Experiment 4 (WS = low vs. high pure tone)					
1	WS-SEQ	1.31	11.5	0.002	0.27	3.7	0.062	0.11
2	FP_{n-1}	2.62	152.6	0.001	0.83	2.9	0.067	0.09
3	FP_n	2.62	24.7	0.001	0.44	0.1	0.812	0.00
4	WS-SEQ × FP_{n-1}	2.62	3.4	0.040	0.09	3.1	0.058	0.09
5	WS-SEQ × FP_n	2.62	5.9	0.007	0.16	0.4	0.592	0.01
6	FP_{n-1} × FP_n	4.124	89.9	0.001	0.74	1.9	0.121	0.06
7	WS-SEQ × FP_{n-1} × FP_n	4.124	0.6	0.636	0.02	0.6	0.594	0.02

Note. *Effect size:* partial η^2; FPs: 1000, 2500, 4000 ms; *factors:* WS-sequence (WS-SEQ: repetition of WS identity vs. shift of WS identity), previous foreperiod (FP_{n-1}: short vs. medium vs. long), current foreperiod (FP_n: short vs. medium vs. long).

preparation in short FP_n trials is substantially influenced by associative learning of sensorimotor connections between WS and IS, including the time period (i.e., FP) between them.

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Appendix 1

See Tables 1 and 2.

References

Bargh, J. A., & Gollwitzer, P. M. (1994). Environmental control of goal-directed action: Automatic and strategic contingencies between situations and behavior. *Integrative Views of Motivation, Cognition and Emotion, 41*, 71–124.

Baumeister, A. A., & Joubert, C. E. (1969). Interactive effects on reaction time of preparatory interval length and preparatory interval frequency. *Journal of Experimental Psychology, 82*, 393–395.

Bourne, L. E. (1966). *Human conceptual behavior*. Boston, USA: Allyn and Bacon.

Bouton, M. E., & Moody, E. W. (2004). Memory processes in classical conditioning. *Neuroscience and Biobehavioral Reviews, 28*, 663–674.

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision, 10*, 433–436.

Correa, A., Lupiáñez, J., Milliken, B., & Tudela, P. (2004). Endogenous temporal orienting of attention in detection and discrimination tasks. *Perception and Psychophysics, 66*, 264–278.

Coull, J. T., & Nobre, A. C. (1998). Where and when to pay attention: The neural system for directing attention to spatial locations and to time intervals as revealed by both PET and fMRI. *Journal of Neuroscience, 18*, 7426–7435.

de Wit, S., & Dickinson, A. (2009). Associative theories of goal-directed behaviour: A case for animal–human translational models. *Psychological Research, 73*, 463–476.

Elliot, R. (1970). Simple reaction time: Effects associated with age, preparatory interval, incentive-shift, and mode presentation. *Journal of Experimental Psychology, 9*, 86–107.

Glenberg, A. M., & Swanson, N. G. (1986). A temporal distinctiveness theory of recency and modality effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12*, 3–15.

Gondan, M., Lange, K., Rösler, F., & Röder, B. (2004). The redundant target effect is affected by modality switch costs. *Psychonomic Bulletin and Review, 11*, 307–313.

Gottsdanker, R. (1980). Aging and the maintaining of preparation. *Experimental Aging Research, 6*, 13–27.

Grice, G. R. (1968). Stimulus intensity and response evocation. *Psychological Review, 75*, 359–373.

Hackley, S. A. (2009). The speeding of voluntary reaction by a warning signal. *Psychophysiology, 46*, 225–233.

Hackley, S. A., Langner, R., Rolke, B., Erb, M., Grodd, W., & Ulrich, R. (2009). Separation of phasic arousal and expectancy effects in a speeded reaction time task via fMRI. *Psychophysiology, 46*, 163–171.

Harris, J. A. (2006). Elemental representations of stimuli in associative learning. *Psychological Review, 113*, 584–605.

Hebb, D. O. (1955). Drives and the C.N.S. (conceptual nervous system). *Psychological Review, 62*, 243–254.

Hommel, B. (2009). Action control according to TEC (theory of event coding). *Psychological Research, 73*, 512–526.

Karlin, L. (1959). Reaction time as a function of foreperiod duration and variability. *Journal of Experimental Psychology, 58*, 185–191.

Klemmer, E. T. (1957). Simple reaction time as a function of time uncertainty. *Journal of Experimental Psychology, 54*, 195–200.

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.

Logan, G. D. (1990). Repetition priming and automaticity: Common underlying mechanisms. *Cognitive Psychology, 22*, 1–35.

Los, S. A., & Agter, F. (2005). Reweighting sequential effects across different distributions of foreperiods: Segregating elementary contributions to nonspecific preparation. *Perception and Psychophysics, 67*, 1161–1170.

Los, S. A., & Heslenfeld, D. J. (2005). Intentional and unintentional contributions to nonspecific preparation: Electrophysiological evidence. *Journal of Experimental Psychology: General, 134*, 52–72.

Los, S. A., Knol, D. L., & Boers, R. M. (2001). The foreperiod effect revisited: Conditioning as a basis for nonspecific preparation. *Acta Psychologica, 106*, 121–145.

Los, S. A., & Schut, M. L. J. (2008). The effective time course of preparation. *Cognitive Psychology, 57*, 20–55.

Los, S. A., & Van den Heuvel, C. E. (2001). Intentional and unintentional contributions to nonspecific preparation during reaction time foreperiods. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 370–386.

Machado, A. (1997). Learning the temporal dynamics of behavior. *Psychological Review, 104*, 241–265.

Martin, E. (1968). Stimulus meaningfulness and paired-associate transfer: An encoding variability hypothesis. *Psychological Review, 75*, 421–441.

Moore, J. W., Choi, J. S., & Brunzell, D. H. (1998). Predictive timing under temporal uncertainty: The time derivate model of the conditioned response. In D. A. Rosenbaum & C. E. Collyer (Eds.), *Timing of behavior* (pp. 3–34). Cambridge, MA: MIT Press.

Näätänen, R. (1971). Non-aging foreperiod and simple reaction time. *Acta Psychologica, 35*, 316–327.

Näätänen, R., & Merisalo, A. (1977). Expectancy and preparation in simple reaction time. In S. Dornic (Ed.), *Attention and performance VI* (pp. 115–138). Hillsdale, NJ: Lawrence Erlbaum.

Niemi, P., & Näätänen, R. (1981). Foreperiod and simple reaction time. *Psychological Bulletin, 89*, 133–162.

Quinlan, P. T., & Hill, N. I. (1999). Sequential effects in rudimentary auditory and visual tasks. *Perception and Psychophysics, 61*, 375–384.

Rabbitt, P. M. A., & Vyas, S. (1980). Actively controlling anticipation of irregular events. *Quarterly Journal of Experimental Psychology, 32*, 435–446.

Requin, J., & Granjon, M. (1969). The effect of conditional probability of the response signal on the simple reaction time. *Acta Psychologica, 31*, 129–144.

Rescorla, R. A., & Wagner, A. R. (1972). A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and nonreinforcement. In A. H. Black & W. F. Prokasy (Eds.), *Classical conditioning II. Theory and research*. New York: Appleton-Century-Crofts.

Roediger, H. L., 3rd., & Blaxton, T. A. (1987). Effects of varying modality, surface features, and retention interval on priming in word-fragment completion. *Memory and Cognition, 15*, 379–388.

Schröter, H., Frei, L. S., Ulrich, R., & Miller, J. (2009). The auditory redundant signals effect: An influence of number of stimuli or number of percepts? *Attention Perception and Psychophysics, 71*, 1375–1384.

Schröter, H., Ulrich, R., & Miller, J. (2007). Effects of redundant auditory stimuli on reaction time. *Psychonomic Bulletin and Review, 14*, 39–44.

Smallwood, J., Nind, L., & O'Connor, R. C. (2009). When is your head at? An exploration of the factors associated with the temporal focus of the wandering mind. *Consciousness and Cognition, 18*, 118–125.

Spence, C., Nicholls, M. E., & Driver, J. (2001). The cost of expecting events in the wrong sensory modality. *Perception and Psychophysics, 63*, 330–336.

Steinborn, M. B., Rolke, B., Bratzke, D., & Ulrich, R. (2008). Sequential effects within a short foreperiod context: Evidence for the conditioning account of temporal preparation. *Acta Psychologica, 129*, 297–307.

Steinborn, M. B., Rolke, B., Bratzke, D., & Ulrich, R. (2009). Dynamic adjustment of temporal preparation: Shifting warning signal modality attenuates the sequential foreperiod effect. *Acta Psychologica, 132*, 40–47.

Stuss, D. T., Alexander, M. P., Shallice, T., Picton, T. W., Binns, M. A., MacDonald, R., et al. (2005). Multiple frontal systems controlling response speed. *Neuropsychologia, 43*, 396–417.

Taatgen, N. A., Huss, D., Dickison, D., & Anderson, J. R. (2008). The acquisition of robust and flexible cognitive skills. *Journal of Experimental Psychology: General, 137*, 548–565.

Töllner, T., Gramann, K., Müller, H. J., & Eimer, M. (2009). The anterior N1 component as an index of modality shifting. *Journal of Cognitive Neuroscience, 21*, 1653–1669.

Tulving, E., & Thompson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review, 80*, 352–373.

Turatto, M., Benso, F., Galfano, G., & Umiltà, C. (2002). Nonspatial attentional shifts between audition and vision. *Journal of Experimental Psychology: Human Perception and Performance, 28*, 628–639.

Vallesi, A., McIntosh, A. R., Shallice, T., & Stuss, D. T. (2009). When time shapes behavior: fMRI evidence of brain correlates of temporal monitoring. *Journal of Cognitive Neuroscience, 21*, 1116–1126.

Vallesi, A., McIntosh, A. R., & Stuss, D. T. (2009). Temporal preparation in aging: A functional MRI study. *Neuropsychologia, 47*, 2876–2881.

Vallesi, A., & Shallice, T. (2007). Developmental dissociations of preparation over time: Deconstructing the variable foreperiod phenomena. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 1377–1388.

Vallesi, A., Shallice, T., & Walsh, V. (2007). Role of the prefrontal cortex in the foreperiod effect: TMS evidence for dual mechanisms in temporal preparation. *Cerebral Cortex, 17*, 466–474.

van Dantzig, S., Pecher, D., Zeelenberg, R., & Barsalou, L. W. (2008). Perceptual processing affects conceptual processing. *Cognitive Science, 32*, 579–590.

Van der Lubbe, R. H. J., Los, S. A., Jaśkowski, P., & Verleger, R. (2004). Being prepared on time: On the importance of the previous foreperiod to current preparation, as reflected in speed, force and preparation-related brain potentials. *Acta Psychologica, 116*, 245–262.

Verbruggen, F., & Logan, G. D. (2009). Automaticity of cognitive control: Goal priming in response–inhibition paradigms. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*, 1381–1388.

Verguts, T., & Notebaert, W. (2008). Hebbian learning of cognitive control: Dealing with specific and nonspecific adaptation. *Psychological Review, 115*, 518–525.

Wagner, A. R. (2008). Evolution of an elemental theory of Pavlovian conditioning. *Learning and Behavior, 36*, 253–265.

Zahn, T. P., Kruesi, M. J., & Rapoport, J. L. (1991). Reaction time indices of attention deficits in boys with disruptive behavior disorders. *Journal of Abnormal Child Psychology, 19*, 233–252.

Zahn, T. P., & Rosenthal, D. (1966). Simple reaction time as a function of the relative frequency of the preparatory interval. *Journal of Experimental Psychology, 72*, 15–19.